Designing and making in a school context: A process model and practical insights

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Abstract

Teaching 21st century skills, STEM (science, technology, engineering, mathematics) subjects and programming for children is the future in education. This thesis was inspired by the project ordered by INTERACT research unit from the University of Oulu, and the goal was to familiarize school children with programming and digital fabrication while collecting research material for INTERACT research unit. Research unit wanted a research material on a project that combines design and making in school context and utilizes University of Oulu Fab Lab. The idea was to conduct a making (digital fabrication) project with children and research it. This thesis is based on the experiences of the project and aims to answer a research question: "What kind of process model supports design and making in school context?".

This research was done using qualitative research methods. This thesis views the social aspects of people in the school system, their relationships, goals, and actions. A lot of data was collected about human beings, their experiences, and reflections. Sessions with children were video and audio recorded but also reflected by project members and children themselves. Gathered data was analyzed using content analysis. The main result of this thesis is a reflective design process model that supports design and making in the school environment. In addition to that, this thesis explain what kind of actors are involved in the process, such as children, teachers, schools, researchers, parents, university and so forth. It describes the goals that needs to be taken into account; most importantly from curriculum and teaching point of view, but also from the IT (Information Technology) point of view. This process could generate more skillful programmers, designers, makers, if this kind of design and making projects could be introduced to school environment. Thesis also enlightens the working in the school context and the pros and cons relating to it. School context is best for projects that focus more on learning goals than end results and outcomes. Results are finally analyzed in light of having digital fabrication and making part of everyday school work.

Keywords
design, making, digital fabrication, children, school context, education, Fab Lab

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Abbreviations

3D	Three-Dimensional
CAD	Computer-Aided Design
CNC	Computerized Numerical Control
DBL	Design-based Learning
DIY	Do It Yourself
ICT	Information and Communications Technology
IE	Innovation Education
IoT	Internet of Things
IT	Information Technology
MIT	Massachusetts Institute of Technology
NGSS	Next Generation Science Standards
PAR	Participatory Action Research
RDBL	Reflective Design-Based Learning
STEM	Science, Technology, Engineering, Mathematics

Contents

1. Introduction

The purpose of this study is to create a process model that helps the reader to implement designing and making in the school context. The outcome is mainly focused on researchers to exploit, but it can also be applied by primary and high school teachers. The guidelines can be used as they are or take guidelines here and there and suit them to the model of your own. The outcome of the thesis is based on literature and to experiences in a project done at the University of Oulu.

One of the main motivations for the study comes from the new curriculum which was appointed in 2016 by the Finnish national board of education. This new curriculum introduced programming in Finnish primary school teaching. Design and making projects such as our project support and educate programming for children. You can educate the basics of programming or more advanced things, depending on the topic of the project or the skills that children possess. The other major motivation factor is to teach 21st century skills for children. It teaches ICT (Information and Communications Technology) and information skills, but also digital literacy (Thijs et al., 2014 in Bekker et al., 2015). These skills are important due to lack of really skillful programmers here in Finland (Liukas & Mykkänen, 2014). Iivari and Kinnula (2018) also imply that children should embrace a new role called a protagonist regarding technology development. This role promotes technology development skills and critical reflection towards the role of technology in their daily life. This is important due to the fact that digitalization is so fast paced around us.

The main concepts in prior research are innovative education, making and designing in general, how to apply them with children in the school context and the educational aspects that need to be taken into account. The main goal of Innovation Education (IE) is to find solutions to needs and problems in our environment. It can be used for redesigning or enhancing current solutions or products. The innovation process is the driving force in Innovative Education and students should use their knowledge from all sorts of sources. (Thorsteinsson, Denton, Page and Yokoyama, 2005.) Innovation Education is a way to teach creative skills for children. It is about finding a solution for a need or a problem, which can be found from children's surroundings. Its goal is to apply and integrate gathered knowledge across life experience and the curriculum. (Thorsteinsson & Denton, 2003.)

Making has a movement called the Maker Movement which is a motion of hobbyist, tinkerers, hackers, engineers and artists which design and build objects exploiting various materials and creativity for both useful and playful end (Martin, 2015). Sheridan et al. (2014) tell that making is an activity which takes place in making spaces such as Fab Lab. This activity is a creative production in science, engineering, and art where anyone can blend digital physical technologies to examine ideas, develop technical skills and design products. The Fab Lab is a laboratory where people can freely use different tools to make things. Tools like laser cutters, 3D printers and computers can be found from the laboratories and each laboratory has the same tools so that projects can be done in any Fab Lab. Teachers' role in making is to be facilitator and enabler. Students need to be active in making, so supporting and tutoring happens automatically. (Schön et al., 2014.)

The third major topic in this thesis is design thinking and designing in school context. Design thinking is a method which proposes a solution-based approach to problem-solving. It can be used in dealing with complex unclear or unknown problems. The defining is done by understanding the human needs, re-framing the problem using human-centric approach, creating multiple ideas in brainstorming sessions, and choosing a hands-on approach in prototyping and testing. (Dam & Siang, n.d.) Smith, Iversen and Hjort (2015) introduce a model which is built for school environments. It is designed to support teachers' and students' ability to carry out a design process and at the same time increase an understanding of the value for design thinking in teaching.

Rode et al. (2003) tell that design work has to fit on the school's curriculum. Iivari and Kinnula (2016) use the model of Chawla and Heft (2002) and discuss how designing fits in the school context. School context is best for projects that focus more on learning goals than high-quality outcomes. It is important to remember that the school's main task is to improve children's skills and to ensure that they become respected members of society.

The Maker Movement and digital fabrication have come to schools worldwide, also designing is heavily used in education. These two combined with the goals and process of Innovation Education are great foundation to this thesis. The main contribution of this thesis is to create a process model that supports design and making in the school environment, so the research question is:

- What kind of a process model supports design and making in the school context?

This will be accomplished by combining the models from the previous research to the project's model and creating a model that supports this kind of design work in the school context. The research method used is qualitative research due to empiric nature of the research.

The thesis is structured as follows. First, it will introduce the prior research starting from innovation education and moving forward to explaining maker movement and digital fabrication and how to involve it in education. Then it will continue with design thinking and how to design it with children and in the school context. The prior research is then summarized focusing on process stages, goals, actors and school context. After that, it will discuss the research methods that were used during the research and how it was gathered and analyzed. Next, it summarizes the key points of the project and tell about the process stages used, the goals had, actors that participated and how school context affected the project. Discussion chapter will introduce the model created based on the prior research and the experiences gained from the project. It will also discuss if Fab Labs could be introduced to Finnish schools and their potential benefits. The study is concluded with the conclusion of the thesis and references that were used in this study.

2. Innovation Education

The Innovation Education project has been developed from the early ’90s in Icelandic elementary schools and for one reason or another the movement is researched and published by them only. The movement started after meeting with concerned individuals that wanted to inspire young innovators to develop their ideas. A working group was created, and the goal was to create a connection between schools and workplaces with innovation. Companies that were interested came along and department in the Technical College of Iceland started to bring the ideas to market. (Thorsteinsson, 1998.)

After school, the community was established, but it became soon apparent that the content should be integrated with ordinary school work and Innovation Education was born. The idea is that everyone is creative, and the creativity can be developed further with supporting student’s own ‘subject knowledge’ ideation. The development group also decided to bring Innovation Competition alongside with the teaching which became an annual event. During the years development group has worked with the concept and has created it further. (Thorsteinsson, 1998.) The concept is explained in the next chapter.

2.1 Innovation Education explained

Thorsteinsson, Denton, Page and Yokoyama (2005) explain that the main goal of Innovation Education (IE) is to find solutions to problems and needs in our environment. It is also suitable for redesigning or enhancing current solutions or products. The innovation process is the driving force in IE and students should use their knowledge from all kinds of sources. Jónsdóttir, Page, Thorsteinsson and Nicolescu (2008) emphasizes that IE develops students’ ideation skills, which in individual level helps students to take an active part in society and to deal with the world better. Thorsteinsson et al. (2005) add that IE stimulates and develops students’ creative abilities, but it also teaches processes such as; identifying a context, evolves students’ own realization and concepts with suitable models. IE develops and encourages initiative skills and increases students’ self-image. Finally, IE can also improve students’ awareness of “objects” ethical values during teaching ways to enhance their environment.

Innovation Education model should not be taken or used too strictly because a lot depends on the context of the innovation. Innovations are always different, and innovators use unique processes, therefore it is hard to judge if one approach is better than others. IE is not created to be too advanced, but it focuses on basic development with basic problem identification, tools, materials, and equipment. There are more developed classes in the future for those who need; IE, on the other hand, is taught by class teachers in normal classrooms. (Thorsteinsson et al., 2005.)

According to Thorsteinsson and Denton (2003), there are seven phases in the Innovation Education working process, namely:

1. Finding needs
2. Brainstorming
3. Finding the initial concept
4. Sketching, modeling and developing the technical solution
5. Making model/prototype
6. Making poster
7. Presentation

In the first phase students search and identify problems or needs from their environment to work with. They are supported to find these problems and needs from the Internet, newspapers, speaking to people, watching the television, going to shops. The findings are then written down and brought to school for discussion with the staff. The staff can then help the students to explore the problem/need in order to fully understand the developed concepts. In the next phase, students brainstorm possible solutions together for these identified needs with the support of the teacher. After the brainstorming student chooses the topic he/she wants to work with after discussing with the teacher about it. In the fourth phase students are encouraged to sketch, model and develop the technical solution to gain a better understanding of the concept and its' possible solutions; the phase involves self-communication and teacher support. Making a prototype is next in line and it is done using equipment and materials found in a regular classroom. The idea is not to fully develop them but to make a simple quick model to give an idea of the solution. In the sixth phase, students make posters for displaying their work and as a presentations' basis. The poster also reflects an individual's learning process. Posters include for example drawings, illustrations, and even 3D modeling. The poster explains how the solution works, where and who is going to use it, where and how it will be used, and what materials can be used creating it. Finally, the solution and poster will be presented to others. It helps students to understand the topic deeper, but it also challenges students to develop their communication skills and getting constructive feedback from others. (Thorsteinsson et al., 2005.)

2.2 Pedagogy of the Innovation Education

The process of innovation is a clear way to teach creative skills for students and the steps above are the phases for it. Finding a solution for a need or a problem found one's surroundings and carried it to a realization in the form of the model. IE processes goal is to apply and integrate gained knowledge across life experience and the curriculum. (Thorsteinsson & Denton, 2003.)

Thosrteinsson and Denton (2003) explain that in innovative work the student's idea and his/her individuality are merged because the student is working with something needed by themselves from their own environment. These personal connections are an important motivating factor for the children. The student's intuition is strengthened by developing a model and supports an understanding of the inner reality of the prototype and its possibilities. The innovative work grows the individual and develops new images for the student's worldview. Murphy, Lunn and Davidson (2002) add that students need also improve their own practice in order to communicate, understand and solve problems.

IE classes require a different kind of approach and role in teaching. The teacher should focus on the students' in a holistic manner and support their concepts instead of judging them. Different work methods are introduced to students to generate and develop ideas and teacher sets himself/herself as equals with the students during the process. The teacher supports students to find problem solutions and functionality to designs. (Thorsteinsson & Denton, 2003.)

Child's creative wisdom needs to be kept alive and motivated by the teacher and every concept and idea that the child creates need to be treated as valid. Ideas need to be supported even if the concept does not succeed at first. The concept itself is valuable and just awaits the right development methods to become a reality. The child and the project he/she is creating should be looked as a whole. This non-judgemental way encourages more imaginatively ideation. (Thorsteinsson & Denton, 2003.)

Basic education is the platform of educating students, but they also need to work with things that interest and allow them to learn from their failures and mistakes. Innovative education gives students the possibility to use their talents and flexibility of IE to support it. This method especially supports highly creative children who can be misunderstood in the traditional class environment. (Thorsteinsson & Denton, 2003.)

Thorsteinsson (1998) explains that the main concept of IE is creativity which can be found from everyone and better creativity means more quality in solutions that one does in everyday life. This can strengthen society in the long run when people are more qualified to modify their environment with creative thinking. This also supports ethical thinking, because students have to work with real-life problems and take responsibility which increases their understanding of helping and shaping society.

3. Maker movement and Digital Fabrication

The Maker Movement is a growing movement of tinkerers, hobbyists, hackers, engineers and artists that design and build objects from the different material using their creativity for both useful and playful end (Martin, 2015). Its name can be traced to 2005 when *Make* magazine was founded and in the first Maker Faire which was held in 2006. As the founder of Maker magazine Dougherty (2012) says: “Maker Faire, which started in the Bay Area in 2006, a year after the magazine, expanded this idea of learning and community and created a space where readers of the magazine could get together to extend the conversation. At the Faire, a maker could put an object they created up on a table and have people ask them about it. Having that kind of conversation with a range of people is the essence of the magazine, of the Faires—and perhaps of the whole movement.” (p. 11).

The term *making* had been throughout time related to crafts and hobbies like woodworking, electronics, and sewing. Alongside these activities, there have been added more modernize crafts in recent years. Digital fabrication online networks and tools make it easy to share, compare, critique designs, ideas and information of the projects. (Martin, 2015.)

This chapter explains what making is, Maker Movement and its manifesto. It will also discuss some of the movements that make up the Maker Movement such as Digital Fabrication and more precisely Fab Lab. Finally, the Maker Movement in education is defined.

3.1 The Maker Movement

The research refers to both constructionism and constructivism as core pedagogical drivers of making. Constructionism means that the process and experience of building something digital or physical produces a rich context for developing and representing understanding. Constructivism refers to the ways how a wide variety of experiences construct the understanding of individual learner. (Martinez & Stager, 2013; Resnick & Rosenbaum, 2013.)

There is not a single definition for making. Honey and Kanter (2013) define that to make is “to build or adapt objects by hand, for the simple personal pleasure of figuring out how things work” (p. 4). Sheridan et al. (2014) explain making activities (which take place in making spaces), that they are creative production in science, art, and engineering where anyone can blend physical and digital technologies to examine ideas, develop technical skills and design new products. Blikstein (2013) focuses on digital fabrication labs which is closely related to making and explains that it is a merge of tinkering, computation, and engineering.

The term *maker* can be defined as people who design and create things on their own time because they find it rewarding to tinker, make, discover, problem solve and share about their learnings (Kalil, 2013 in Martin 2015). Dixon and Martin (2014) explain that being a maker means being creative, building things, solving problems, having fun, collaborating, doing social good and learning. Dougherty (2013) describes that makers are enthusiasts that learn about technology by playing with it.

When talking about the Maker Movement Dougherty (2012) does not want to use a term *inventor*, because most people do not like to be called that way. The term *maker* is more suitable because it can be said from each and one of us no matter what our goals are or how long life we live. You can be a maker in everyday life, for example, cooking for your family or gardening in your backyard.

Schön, Ebner and Kumar (2014) explain that the idea of the Maker Movement is to develop and create new things using the modern tools such as 3D printer, in labs, workshops or open spaces. It is generated from do-it-yourself work and innovative forms of productions. Making is not entirely digitally driven, but it is almost entirely built on the development of the “Internet of Things” (IoT). The IoT is a network of small computers or digital tools and devices connected to each other, which are exploited to produce or create new products.

Back in the day, it was more common that people expressed themselves as tinkerers. You could, for example, fix your car or make your own clothes if you had good tinkering skills. Dougherty (2012) thinks that over the decade's people have lost some of that tinkering mentality, but he sees that it is starting to come back. While the ability is not treasured as much as before, people find it enriching when they create something new and learn new skills.

Makers are enthusiasts from their hearts, just like people from Silicon Valley in the early days of the computer industry. This aspect of the computer industry has been lost because these devices they created have become widespread and easy to use so people do not have to be enthusiasts to use them anymore. The makers from the early days were basically playing with technology because they really did not know what they wanted computers to do nor they did not have any specific goals in their minds. They learned by trying different things, making, breaking things and putting them back together. (Dougherty, 2012.)

Those early makers belonged in micro-communities that were formed from like-minded people with the same hobbies and activities. Today’s makers can enjoy from interconnectedness that has built up a movement. The Internet has helped the movement to grow and is driven by it, but events like Maker Faire allow people to mix things from different fields. These mashups lead to various exciting creations. If you share a common passion and enthusiasm then you seem to belong together whether your field is arts, science or crafts. (Dougherty, 2012.)

3.2 Maker Movement Manifesto

Hatch (2013) has created a manifesto for maker movement that has nine principles on it. The nine principles are: Make, Share, Give, Learn, Tool up, Play, Participate, Support and Change. Making is one of the essential parts of being a human, we need to create, make and express ourselves to feel whole. Makerspace is a place where people with different backgrounds get together to make things, those people will not spend their time there because they have to, but because they want and need to make things.

Sharing is a crucial part of making because you cannot make without sharing. Sharing of what you know and have made for others gives the feeling of wholeness for a maker. The true satisfaction comes from sharing what you have achieved. Sharing is not all about getting the satisfaction out of it, but passing the knowledge is also a big part of making. Individuals develop their skills this way if the help is near and easily available. Another selfless and satisfying thing in the making is giving away something you have made. It is a very satisfying thing to give something away to others that has a small piece of yourself put into it even though it is an object. The receiver also usually values the gift more if it is handmade than bought from a store. The result of making can also give great value to the society not just to a single person. (Hatch, 2013.)

Learning is an important part of making whether you are a beginner or professional in a practice that you make. Individual must learn to make and constantly evolve your processes and techniques. The education these days tends to give the formula which is applied without thinking and observing more deeply how it can be used in real life. As Hatch (2013) says: “I always found the order we did things in physics class backward. Instead of being taught the formula for determining the ratio of the required output force to the input force and then trekking to the lab to see how a lever works, it makes more sense to first observe the lever in action and then learn the formula for it. This is how the principle was figured out in the first place, through observation. You observe an effect, then build a theory to fit the observation.” (p. 20). Experiencing the facts is much slower than memorizing them, but only after experiencing you really own the fact. After familiarizing and practicing the practice you also get the pleasure from teaching and sharing what you have learned.

Maker Movement would not be anything without proper tools and maker needs to have access to the right tools for the project to happen. Maker Movement and Fab Labs became possible in a first place because the tools became cheap, powerful and easy to use, but for an individual, it is too expensive. Luckily the community provides everything needed for an individual maker. Well-equipped makerspace enables to make a variety of projects, attracts people who provide knowledge and sharing. The community needs also a staff who manages the lab/space and helps makers with the tools and problems they might face. (Hatch, 2013.) Table 1 below is an example list of tools that are needed for creating a community.

Table 1. List of tools needed in making (Hatch, 2013, p. 24-26)

• Laser Cutters	• Sheet metal brake (16 gauge × 50 inch)	• Wood sanders
• CNC milling machine(s)	• Rotary sheet metal punch	• Wood scroll saws
• Manual milling machine(s) with digital readouts	• Sheet metal corner notcher	• Wood lathe
• Manual lathe(s) with digital readouts	• English wheel and planishing hammer	• Drill presses
• 3D printer(s), consumer and commercial grade	• Sheet metal shear (6 gauge × 50 inch)	• Granite surface plate with digital height gauges
• 3D scanner	• Sheet metal roller (16 gauge × 50 inch)	• Compressed air throughout shop
• CNC (computer numerical control) waterjet cutter (4 × 8 foot)	• Sandblast cabinet	• Compressed air hand tools
• Vacuum forming system	• Metal grinders and sanders	• 30 or more design computers
• Heat strip bending system	• Metal chop saw	• 30 or more copies of or licenses for Autodesk Inventor, Maya, 3D Max, 123D Make, AutoCAD software
• Injection molding system	• Metal horizontal band saw	• 30 or more copies of or licenses for Adobe Illustrator, Photoshop, Acrobat
• Commercial grade sewing machines	• Metal vertical band saw	• 30 or more copies of or licenses for National Instruments LabVIEW Professional development system
• Overlock sewing machine (also known as a serger)	• Electronic testing and soldering equipment	• 8 or more National Instruments multifunction data acquisition devices
• Quilting machine (preferably CNC)	• Large format color printer	• Member storage
• Computer-controlled vinyl cutter	• ShopBot CNC wood router saw (4 × 8 foot)	• Private studios for rent
• MIG (metal inert gas) welders	• Panel saw	• Meeting rooms and/or classrooms
• TIG (tungsten inert gas) welders	• Wood planer	• 12 large work tables
• Handheld plasma cutter	• Wood jointer	• Powder coating system (and large oven)
• Sheet metal spot welder	• Wood band saw	• Free coffee and popcorn
• Retail store	• Wi-Fi	

Hatch (2013) urges makers to be playful in his manifest because the best results arrive when you are having fun during work. Makers should be playful with their ideas, joke around and think about the most extreme solutions for their projects. Playfulness keeps things innovative and rich. The Maker Movement is much about participating with others, of course, some people like to make things in solitude, but most of the time it is preferable to participate or at least share workspace with somebody. We are social creatures and it is more fun to work together than alone. There are different ways to participate in the community; working directly together, participating in societies, attending events, clubs, parties with like-minded people who share the interest. In Maker Movement, there is an annual event called Maker Faire which is held in many locations around the world.

Hatch (2013) insists that the Maker Movement is like any other movement and it needs support to succeed. The support that is needed can be financial, political, institutional, intellectual and emotional. Governments have spent billions of dollars world-wide building institutions of research, learning, experimentation, and development. These institutions, unfortunately, are not usually open for public use and the research is not generally self-directed. All of the research requires funding and approvals from third parties. People that are not from the institution does not get accesses to development and research tools even though they are cheap and easy to use these days. As Hatch (2013) claims that those countries that change their tool access policies will gain huge competitive advantage. Makerspaces have already changed the world so supporting them is crucial. Finally, Hatch (2013) proposes that the Maker Movement changes individual and one should embrace the change, because it will make a person more complete. One can see the world from different point of a view, as it makes a person wonder how things have been done, who has done them and appreciate more hand-made work.

3.3 Different laboratories and studios

Schön et al. (2014) reports that the Maker Movement is a social movement and therefore is not a one man's idea or born at a certain point in time. Multiple sub-development branches have shaped it up throughout time into its current form. The Maker Movement is formed from multiple laboratories and public studios where people are free to make things. These laboratories and public studios are called Fab Labs, Makerspaces and Hackerspaces where you can implement a do-it-yourself (DIY) business model. The things you have created can then be introduced for other makers in events called Maker Faires.

Hatch (2013) explains that the Maker Faires are annual events, which are held in various locations around the world. Thousands of makers come to hang out and participate in these events where people share and experience each other's projects. The primary Faire is located in Northern California, but smaller so-called Mini Maker Faires can be found all over the world. Schön et al. (2014) explain the history behind Maker Faires saying that, all of this started after a magazine called "Make" was published in the year 2005. The magazine focuses on do-it-yourself projects involving robotics, computing, electronics, and other product areas. The first Maker Faire was established by the magazine in 2006. These Faires are trademarked and supervised by the Maker Magazine. Even the White House in the United States of America has hosted its own Maker Faire in 2014 (Dopplick, 2015).

Schön et al. (2014) adds that workshops called "Makerspaces" are another part of the movement. These are commercial studios a lot like Fab Labs and they are equipped with digital fabrication tools such as laser cutters, 3D printers, AutoCAD software and a vinyl plotter that can be used by anyone in exchange of a small fee. The idea of these workshops is to offer open facilities, supporting, friendly and creative atmosphere. The chief executive officer and a founder of the first makerspace Mark Hatch describe the makerspace a workspace or center where like-minded people meet to make things. Besides Fab Lab and makerspaces there is also a more software-oriented movement called “hackerspaces”. Its focus is slightly different than in the previous two and the idea of it is originated in Germany the group called Chaos Computer Club in 2009. Physical rooms are seen as inspirational places for open source developers. The first hackerspace called "c-base station" was established in Berlin; another well-known hackerspace is "NYC Resistor" in New York City, USA. (Schön, Ebner & Kumar, 2014.)

The MIT Fab Lab is short for “fabrication laboratory” and according to their website its motto is: “give ordinary people the right tools, and they will design and build the most extraordinary things”. The idea is originated by Professor Neil Gershenfeld at MIT’s Center for Bits and Atoms. (FAB LAB DC., n.d.)

As previously mentioned, the basis for the Fab Lab started to emerge at the Massachusetts Institute of Technology (MIT) when around the eighties employers and faculty felt that design-deprived engineers were not capable enough of doing actual engineering design work, which had become increasingly more important. In the early 2000s, tools and prototyping equipment prices dropped, which led corporates to move their product development towards to studio/laboratory model. Engineers and designers could now create prototypes in a matter of days instead of months in these studios. This changed the product engineering dramatically. (Blikstein, 2003.)

According to Schön et al. (2014), a Fab Lab is a laboratory where people can freely use a different kind of tools to make and design things. Tools such as 3D printers, laser cutters, and computers can be found from these laboratories and each laboratory has same tools so that same projects can be implemented in any Fab Lab. Some of these tools can be seen in Figures 1, 2 and 3 which are taken from the Fab Lab of University of Oulu. First Fab Lab was opened in 2002 in MIT and thereafter the laboratories have spread across the world. A Fab Lab need to have four essential features to be registered by the Fab Lab foundation. The features are: set of common tools, public access, participation in the Fab Lab network and the signing of Fab Lab Charta. The Fab Lab should be free to access and work, at least for some time.

Figure 1. Fab Lab Oulu – 3D printer

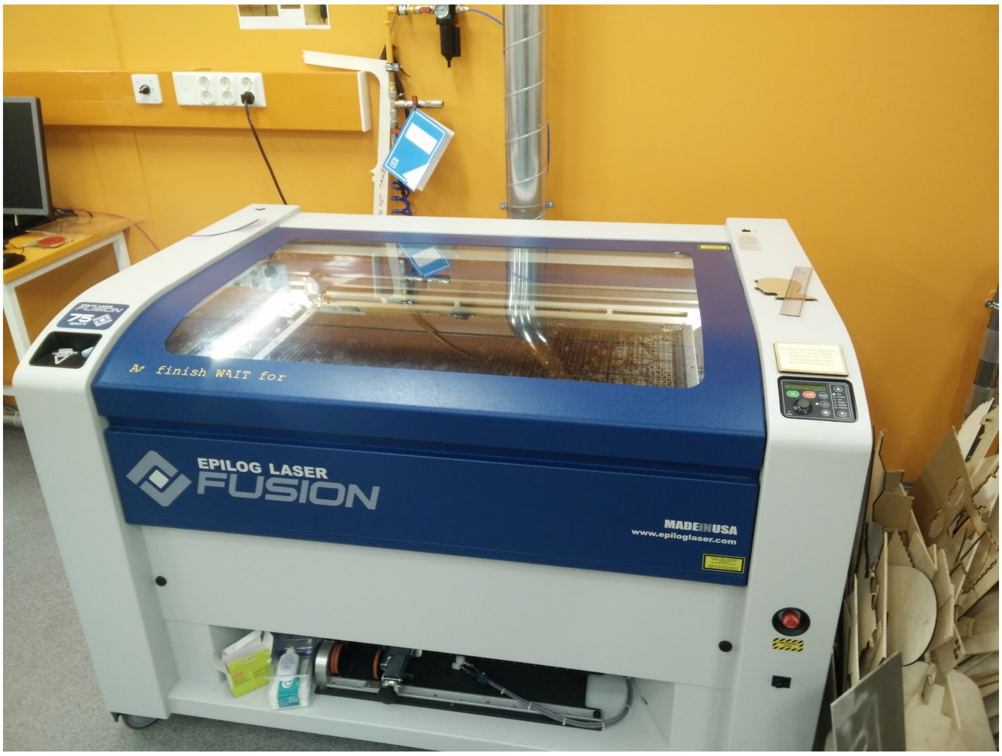


Figure 2. Fab Lab Oulu – Laser cutter

Figure 3. Fab Lab Oulu – Computer and meeting space

The idea is that tools of digital fabrication create material objects from digital designs. First, the designer creates a computer-aided design (CAD) with a computer and some design tool and transfers the model into fabricator. This fabricator then builds the design into a physical instance of it from the stock material that the Fab Lab provides. Whereas Computerized Numerical Control (CNC) mills and laser cutters build parts from acrylic, sheets of wood, cardboard, metal and other flat stock; 3D printers use materials such as ceramic, thermoplastics and powdered metals to build the objects by depositing and binding consecutive layers. (Mota, 2011.)

When comparing with mass manufacturing tools this technology allows to make the production of few or several one of a kind objects at the same price as a series of identical items. It is also very flexible and wastes very little of the stock material, for example, 3D printing prints the object in one single piece that generally needs to be manufactured and assembled from several different parts. Traditional mass production technologies are still more rapid but cannot create objects out of range of materials than the Fab Lab tools do. Most digital fabricators support only one type of material at a time and cannot create finished intricate device in one swoop. (Mota, 2011.)

One important aspect at working in laboratories is safety. According to Rajanen and Rajanen (2019) there are three safety dimensions that needs to be adopted to laboratory working. First dimension is called safety as professional, which means that the professional and experienced maker sets himself/herself as a role model, an example how to be responsible, aware and concerned of safety issues. This example will make others follow the safety procedures as well. The responsibility of a professional maker is also to set, follow and update safety rules. Second dimension is called safety as social responsibility, and in laboratory it means ensuring that digital fabrication laboratory is hazard free space. Organizational decision making is an important social responsibility, because organization is liable of well-being, safety, long-term health and empowerment of staff and makers. Third dimension is titled as safety as environmental responsibility. The environment needs to be taken into account also in digital fabrication, which includes optimizing the use of energy, materials and consumables. Organization needs to recycle, minimize waste and use renewable materials if possible.

3.4 Maker Movement in education

Blikstein (2013) mentions, that at the end of the 2000s, educators and researchers started to examine whether the digital fabrication would be suitable in education. FabLab@School was launched in 2008 by Stanford University and started to build Fab Labs in K-12 schools around the world. Despite being a quite new field in education, the idea behind the movement is much older. Making and digital fabrication are based on three pedagogical and theoretical pedestals, which are constructionism, experiential education, and critical pedagogy. Many theorists such as John Dewey have been questioning the common assumptions of pedagogy and their opinion is that education should be more student-centered, experiential and connected to real-world objects. (Blikstein, 2013.) In critical pedagogy Freire (1974) criticize this so-called “banking education”, where students passively learn and memorize what teachers teach. There is no communication between the students and teacher and decreases student’s critical thinking. Freire also introduced his idea of the culturally meaningful curriculum where inspiration is got from local culture. He also states that learners should go to the “consciousness of the possible” instead of the “consciousness of the real” as this is limiting the thinking. Blikstein (2013) also adds that students should be more connected with meaningful problems in the community or personal level. Creating solutions to those dilemmas would be educational and empowering.

Seymour Papert (1987) thinks that students learning potential would be maximized by arranging environments where their interest and passion flourish. Papert also introduced the idea of using digital technologies in education. Papert’s constructionism states that knowledge construction develops well, when students make, build and share their objects publicly. Blikstein (2013) says that this is also the main core of digital fabrication and making in education. The technology is used as an emancipatory tool, giving powerful tools in the hands of children rather than the way that it is traditionally now used. This also supports the maker way of thinking, different learning styles and creates an environment where students are engaged to concretize their ideas projects. There is rarely a fixed curriculum in a constructionist learning environment, but teachers act as facilitators while children are using technology to build projects.

There have been several projects during the years that have demonstrated that computer is more than communication and information tool, but also a device for expression and construction. Projects such as creating programming video games (Millner & Resnick, 2005) and designing virtual robotic systems (Berland, 2008) are only a few examples. These technologies and toolkits provided the ground for digital fabrication and the maker movement. These projects proved that children can use complex technology rather than just consume technological products. It was also showed how powerful and generative children’s ideas and intellectual passion can be and that in many cases the reason for difficulties was in deficient design and not in students’ cognitive abilities. (Blikstein, 2013.)

After the Fab Lab concept was deployed, tens of invention and robotic workshops were conducted by Blikstein (2013). He found it disappointing that after workshops students did not have any place to continue or deepen their projects. School subjects like sports or music have their own premises, so Blikstein asks why should not inventing or engineering have their own premises? This was the birth of the FabLab@School project as digital fabrication labs would be a solution for learning invention and engineering. These spaces were designed gender-neutral and inviting where students could safely make, build and share their creations. The goal was to attract high-end engineering type students, but also those who just wanted to try technology projects or improve their current projects. (Blikstein, 2013.)

Blikstein (2013) says that the result of these workshops was that students gained more appreciation for manual labor than before, but also from their parents. Students first designed their creations on a computer after various calculations and measurements. All the work was filled with two socially valued practices: mathematics and computation, but still contained building, construction, and hand work. Adding computation tools into the building and making process increased and empowered self-esteem, but also generated more sophisticated projects. This enhanced rather than replaced the powerful and familiar practices that students already possessed so students did not have to create a new identity.

Another benefit in digital fabrication is that it quickens the process of ideation and invention. The student does not have to spend his/her time to solving issues with materials and such, but to concentrate on improving the design. Digital fabrication makes everything more aesthetically pleasing when compared to cardboard prototypes, and it had a big impact on students' self-esteem because it was so close to being a near professional finish. These workshops allowed students to engage in intellectual practices and activities that were not available anywhere else. Digital fabrication gave an experience of new ways of work and new levels of team collaboration. It also helped students to experience a very educational experience of failure and learning how to manage it, which is rarely taught in schools. Several cycles of redesign and failure allowed students to create especially complex and original designs, but made them more tenacious, better at managing intellectual diversity and learned to work in heterogeneous teams. (Blikstein, 2013.)

Schön et al. (2014) use the didactic triangle to explain why maker movement should be implemented in education. The triangle (Figure 4) is composed of student, teacher, and content, which in this case is a set of tools. Children grow up using a different kind of technologies and educators can make use of the familiarity of technology, their playful mindset and easily available technology to help create and make products that relate to their environment. This can challenge and develop their abilities to construct something new and innovative. It meets a wide variety of teaching goals such as Science, Technology, Engineering, and Mathematics (STEM), problem-solving, innovation development and creativity. The student also learns social skills when he/she is discussing and sharing experiences. Making also puts a student to think about the impact that her/his creation can do for society, environment, and ecology. It also gives concrete results such as products or objects and a feeling of achievement, while typical learning results give you grades and results.

Teachers role in the making is also very much different than in typical education because teacher-centered teaching is not a feasible solution. Teachers' role in the maker setting is to be facilitator and enabler. Supporting and tutoring happen automatically because students themselves have to be active. In this environment, there actually is not that big of a gap in expertise or experience between teacher and students. A student can be more experienced with some tools from the beginning or become more experienced during the process; openness of the setting and creative results may lead to that. Learning by teaching and co-creation is a reality and mindset of this approach. This can motivate, surprise and challenge teachers, while students can examine their learning and problem-solving abilities, but also see them as inspirational partners. (Schön, Ebner & Kumar, 2014.)

Digital fabrication tools are special from the perspective of learning and education because the content is real compared with typical learning materials such as textbooks and blackboard. Making also deals with concepts and theories, but practice and transfer are more important. Creating concrete things/products and making own experiences has been seen as important for learning for several centuries. Setting up making tools in the school environment may sound expensive, but the tools are flexible and can be used in diverse ways with students of different ages. Making is not all about the physical materials, because it is also possible to produce digital software in the laboratory. There are several open source products available that also can be used on mobile devices. These mobile applications enable children of any age to create and make because they are so flexible. The last argument is that maker tools are modern up-to-date devices. There are so many different scenarios to use these applications and tools so that it brings a whole lot of opportunities and ideas to innovate. This is very attractive for students, but for teachers also. (Schön, Ebner & Kumar, 2014.)

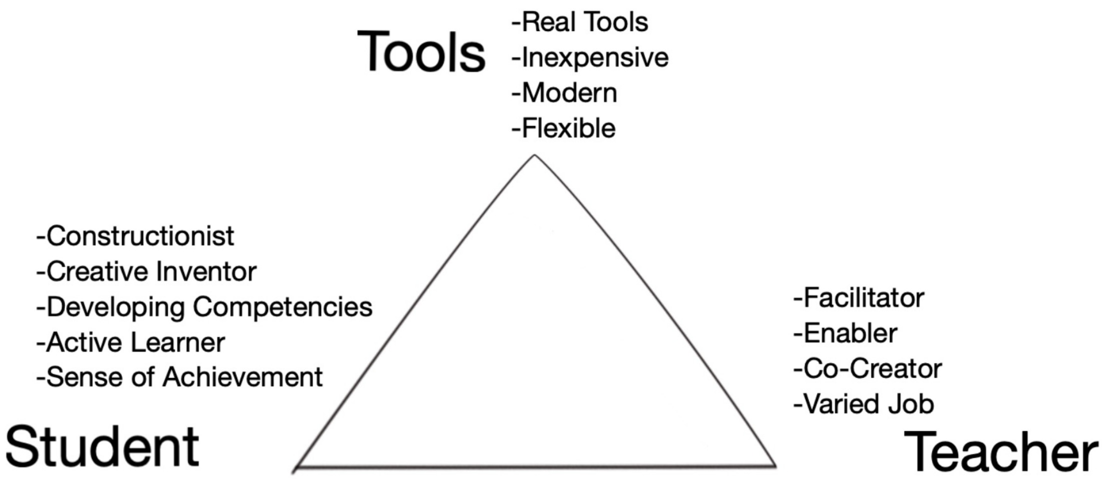


Figure 4. Didactic triangle - Making movement in education (Schön, Ebner & Kumar, 2014, p. 8).

Martin (2015) lists reasons why making is relevant for learning in education. Making fits in education curricular, especially from the engineering point of view seen in Next Generation Science Standards (NGSS). Learning activities are aligned with learning outcomes and it is an efficient way to boost learning. Making allows students to get access to sophisticated tools for thinking and building. It is certified that digital tools increase a new way of thinking, such as computational thinking. Making is creating things, observing how they perform and sharing them with others. As Papert (1993) says that learning: "often happens especially felicitously when it is supported by construction of a more public sort 'in the world'" (p. 142). Learning is powerful when it is driven by recursive feedback, where individuals learn from the actions of their creations.

Playfulness encourages students to experiment, which develops conceptual knowledge and boosts adaptability when facing problems. Failures whether they are large or small can inspire learning as they stray people out of routines into reflective thinking, which increases learning. Making pushes a growth mindset, where anyone can learn the skills to complete the project they imagine with given resources and effort. Growth mindset emboldens challenge seeking, persistence and learning. Making environments usually give students a substantial say in how and what they make. Learning environment that supports students control and autonomy of their efforts support engagement, persistence, the growth of resourcefulness and identity development, but also are more motivating. Making exist within different learning communities, spanning online and in-person contexts, and including people of a wide range of knowledge and ages. This helps students to integrate their interest with strong social support to produce a powerful context for learning. (Martin, 2015.)

There are also some problems in digital fabrication that Blikstein (2013) has noticed during his projects. For example, the limited number of tools in Fab Lab leads to division of labor and may cause discouragement. The assignment may turn out to be complex or difficult while the instructor must remember not to solve the problems for the students, but to maintain a certain distance. On the other hand, the projects should not be too simple in order to ensure continuous learning and avoid getting stuck in a rut.

4. Designing with children in a school environment

This chapter describes how to implement design practices in a school environment. It explains the design process in general and how to use it so that it fits in a class environment. It introduces the so-called Reflective Design-Based Learning (RDBL) framework which describes the developing challenges of an integrated process that can be used at school. It discusses what needs to be considered when planning design practice projects relating to children participation in design. Also, the challenges of designing with children in a school environment are explained. This chapter also defines the children roles during design process mostly focusing on the role called the *child as a protagonist*. Finally, various actors are introduced which take part in the design process with children.

4.1 Design thinking

Design thinking is a design method which presents a solution-based approach to solving problems. It is highly useful in dealing with complex problems that are ill-defined or unknown. The defining is done by understanding the human needs related, by re-framing the problem using human-centric methods, by developing multiple ideas in brainstorming sessions, and by choosing a hands-on approach in prototyping and testing. These five stages will help anyone to adopt the design thinking methods to solve different problems around us. (Dam & Siang, n.d.) Mulder (2017) adds that design thinking is not a fixed protocol, but a different way of thinking. The problem is defined at first, then one looks up for solutions that include the needs and wants.

Brown and Wyatt (2010) mentions that design thinking should not be thought of as a sequence of orderly steps but as a system of overlapping stages. Authors define three spaces called inspiration, ideation, and implementation. The inspiration can be thought as the opportunity or problem that motivates in search for solutions; ideation as the process of idea generation, developing and testing; and the implementation as the passage from the project into people’s hands.

Razzouk and Shute (2012) explain that design thinking can be defined as a creative and analytic process which binds an individual in opportunities to create and prototype models, experiment, collect feedback, and redesign. Good design thinker should possess several characteristics such as ability to visualize, understand human- and environment-centered concerns (meet human needs and consider environmental interests), have systemic vision (use different concepts and procedures to create holistic solutions), predisposition toward multifunctionality (designer should keep the big picture in mind, but at the same time seek different solutions to a problem), ability to use language as tool a (designer should have the ability to verbally explain the design process), affinity for teamwork (designers should possess communication skills to work with other people) and avoiding the necessity of choice (designers should search for different alternatives before making choices or decisions).

4.2 Design thinking process

Dam and Siang (n.d) tell that there are many variants of the design thinking process, but all of them are based upon the works of Herbert Simon and more precisely a book "The Sciences of the Artificial". This model consists of seven major stages, but this thesis will introduce the five-stage model created by the Hasso-Plattner Institute of Design at Stanford (d.school, n.d.). According to d.school these five stages are called empathise, define, ideate, prototype, and test (Figure 5). Chen and Huang (2017) add that the process is iterative, and each stage should produce deliverable outcomes.

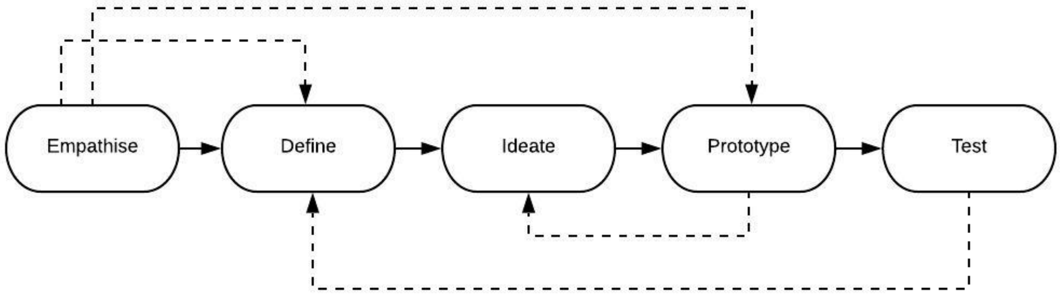


Figure 5. Design thinking process (Dam & Siang, n.d.).

The first stage is called empathise and in this stage, an empathic understanding of people is gained and the problem you are trying to solve. This understanding comes from consulting experts of the field and empathizing, observing and engaging with people to understand their motivations and experiences. Immersing oneself into the physical environment is a good way to gain an understanding of the issues involved. Empathy is a critical part of design thinking because design thinker can set aside her/his own assumptions about the world, so that insight of the needs can be gained from the users. The information gathered at this stage is used during the next stage to get the best possible understanding of the users, their needs and problems which determine the desired product. (d.school, n.d.)

The information which is gathered and created is defined during the next stage. The observations are analyzed and synthesized in order to determine the core problems that are identified up to this point. This stage will help the designers to gather grand ideas to establish functions, features, and elements that will help designers to solve the problems or at least help users to do so. During this stage, designer also starts to advance to the next stage by asking more detailed questions. (d.school, n.d.)

In the third stage of the process, designers start generating ideas. With the previously gathered knowledge, designers can now start to think outside the box to find new solutions to the created problem statement and new ways to view the problem. Ideation techniques such as brainstorming are used to expand the problem space. During the ideation phase, the most important thing is to get many problem solutions or ideas as possible. (d.school, n.d.)

In order to investigate the problem solutions previously created, designers need to generate prototypes of the product or some of its features. Prototypes can be tested and shared within the developer team, in other departments or with people outside the design group. The goal is to identify and experiment with the best solutions for the problems identified during the previous stages. The prototypes are then investigated and either accepted, re-examined and improved or rejected on the basis of users' feedback. After prototyping designers will have a better understanding of the restrictions of the product, but also about the problems and better perspective how end users would think, behave and feel when interacting with the final product. (d.school, n.d.)

The final stage is testing and during this stage, the designers rigorously test the complete product. This is an iterative process and the results found often redefine the problems previously found. This is the last opportunity to understand the user, the conditions of use how people feel, behave and think, and to empathize. On these grounds, the final refinements and alternations are done for the product. (d.school, n.d.)

4.3 Design thinking processes with children

Smith, Iversen and Hjort (2015) introduce a model that is comparable with Stanford University's D-School design model. This model is built for school environments. The goal of this process is to support teachers' and students' ability to carry out an explorative design process and at the meantime increase an understanding of the value for design thinking in teaching. This iterative design process was developed for seventh-grade students and the main stages of this model are 1. *Design brief*, 2. *Field study*, 3. *Ideation*, 4. *Fabrication* and 5. *Reflection*. The process can be seen from Figure 6.

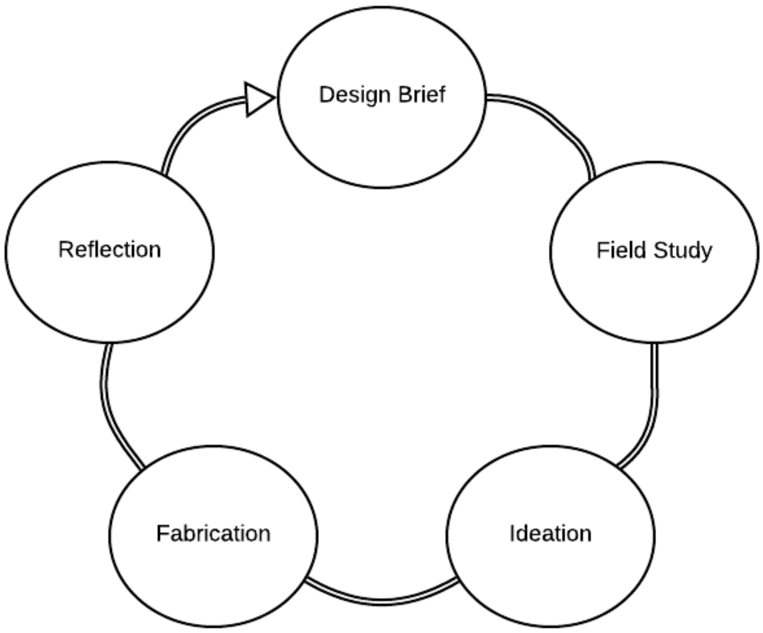


Figure 6. The FabLab@School.dk process model for design thinking in digital fabrication (Smith et al. 2015).

During the design brief phase students frame the complex challenge and the design process is planned. After that, a field study is conducted, i.e. the users and context are researched and explored. At the ideation phase the creative development is done by using different materials and technologies. Then students move to fabrication where mock-ups and prototypes are created using digital technologies. Finally, students reflect what they have learned and developed through the whole design process. (Smith et al., 2015.) Iversen, Smith and Dindler (2017) also included one more phase called *argumentation* (seen in Figure 7) and placed it between the *fabrication* and *reflection* phases, and during that argumentation stage students test the design ideas or products and reflect on the design arguments and moves of the process.

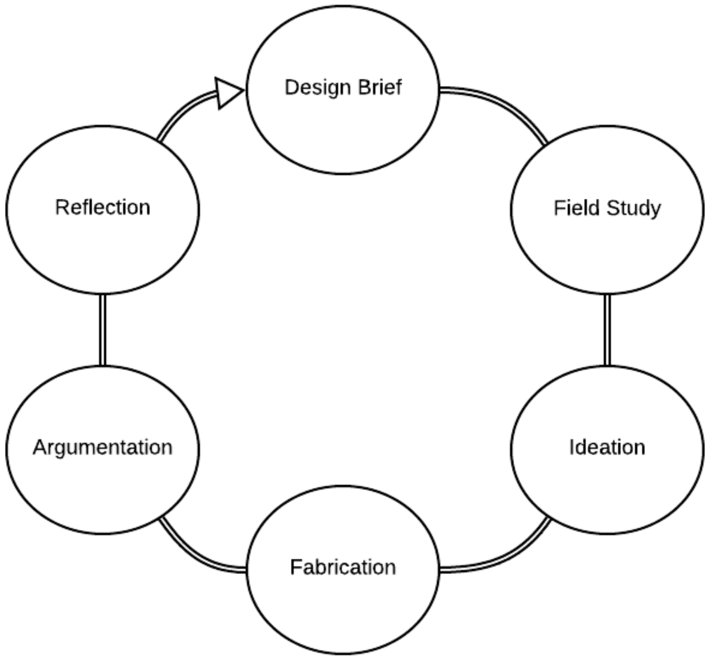


Figure 7. Design activities in an iterative design process model (Iversen et al. 2017).

According to Bekker et al. (2015), teaching digital literacy is important due to increasing the understanding and evaluating for technology and ability to use it. It also gives understanding for technology strategies and principles needed to establish solutions and recognize specific goals. To teach design thinking and digital literacy through design-based learning, Bekker et al. (2015) introduce a *Reflective Design-based Learning* (RDBL) framework (Figure 8). The framework describes different factors that need to be taken into account when teaching design-based learning in a school context.

Gomez et al. (2013) had previously created the *Design-based Learning* (DBL) framework which is created to support higher engineering education including a model for a teacher's role, design elements, project characteristics, social context, and assessment. It was used for analyzing existing engineering DBL activities and propose ideas for DBL teachers to remodel their projects with DBL framework. Bekker et al. (2015) took the model and customized it to fit into primary and secondary school context by adding the 'R' (Reflective learning) into DBL framework, but also paying more attention to the digital characteristics of the learning environment. Practically this means that during the design activity and before moving into the next one, the progress is reflected. The RDBL can only be successful when diverse criteria are met systematically during the entire process. Learning goals need to be always met while teachers can assist in the progress of the process.

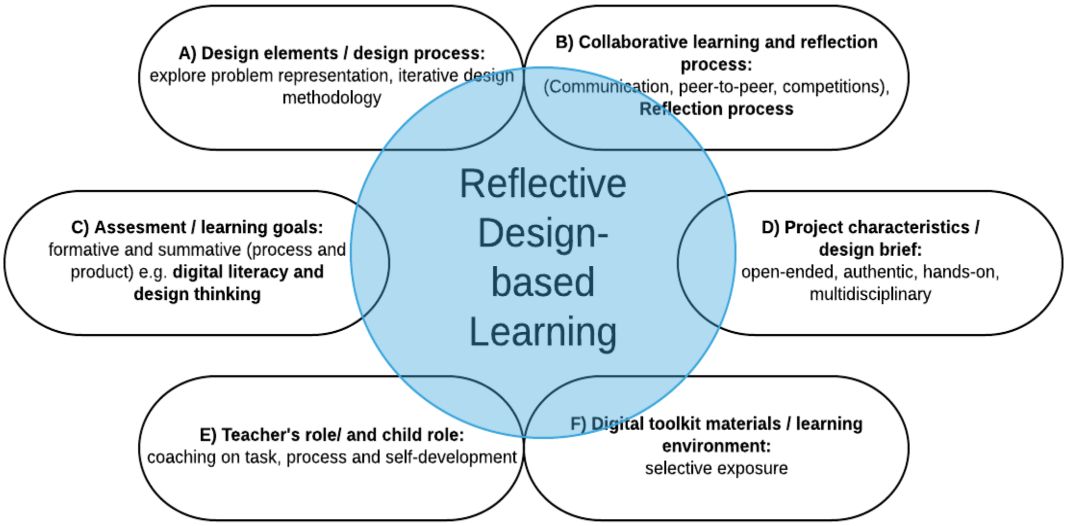


Figure 8. Reflective Design-based Learning framework (Bekker et al. 2015).

The framework includes components from A to F as can be seen from the Figure 8. Component A is called *the elements of a design process.* There are different design processes that can be chosen, for example, the previously mentioned d.school or the model from Iversen et al. (2017). These models describe the steps for the process and the idea of it is to support the learning process. Component B is called *Collaborative learning and reflection process* and according to it, students should reflect their actions during the design activities and in between them. The idea is to support and ease the learning process of the student. The previously mentioned is introduced in an article called *Reflective Transformative Design Process* published by the authors Hummel and Frens (2015). Another great approach is Kolodner's (2002) *Learning-by-designing,* where learners keep design diaries to reflect things they have learned during the process. Alongside the diaries, learners can use whiteboarding technique to reflect the progress and write down the key points they have learned.

Phase C is called *Learning goals and assessment* (Bekker, 2015). Learning goals are related to 21st-century skills and specific goals of courses. Alongside design thinking one of the 21st-century skill is digital literacy, which contains basic knowledge of media literacy, ICT and information skills (Thijs et al., 2014 in Bekker et al., 2015). It is also an ability to understand, use and evaluate technology, but also to understand the technological strategies and principles needed to establish solutions and to recognize specific goals (Voogt & Pareja Roblin, 2010). Learning goals can also be measured in terms of STEM. Component D is *Design brief and project characteristics* and during the design brief ill-defined problems are described; problems that have various ways to be solved. Design briefing improves problem-solving skills and creativity. (Gomez et al., 2013.)

Teacher's and children's role is the component E Teacher's main role is to coach student in design-based learning, the regular way of teaching is in a minor role. The coaching means staging the process, inspiring the student, asking questions and governing reflection. (Kolodner, 2002; Gomez et al., 2013.) The final component F. is called *Properties of learning environment including the digital toolkit.* The goal of digital toolkits is to support digital fabrication by supporting children to swiftly elaborate solutions for problems. In RDBL approach these toolkits are important and as Resnick and Silverman (2005) mention that it is vital for the children that the toolkits are easy to understand, but at the same time, they need to support diverse use. For example, the tool's motor should be easily programmed without knowing the details of the motor itself. The toolkit should support trial and error kind of learning alongside with more structured and disciplined. Finally, as Douma, Bekker and Rijnbout (2015) add that toolkit should support the different interests that children possess. Some children are interested to know and understand the more technical details such as electronics and programming, but others are more interested in how to apply the technology in their designs.

4.4 Designing in school environment

When implementing an interactive design in the school environment; curriculum also has to be taken into consideration. Rode et al. (2003) mention that design topic, ways of working and results have to fit on the country's and/or school's curriculum. The design has to promote learning in a way that curriculum defines. Therefore, it is mandatory for participants to have a general knowledge about the curriculum of the target school.

Rode et al. (2003) also discuss working in a school environment in general. They point out that it is important to have a member who has school-teaching experience, in order to have an understanding about what is too advanced or alternatively patronizing to certain age groups. Running this kind of design sessions in school means that designer is all but in control about the environment and situations. Designer has to be prepared for so many different scenarios that can happen with children. For example, one also cannot be sure that the desired classroom is available for sessions. To avoid unexpected problems, designers have to understand that planning is everything. It is vital for the design sessions but also required from the administrative point of view. Schools and teachers generally want to know beforehand what the sessions include and how it fits into their plans and curriculum, but also how it fits into school's policies. Once the lesson dates are set, you should avoid canceling them due to harm it causes for teacher's timetables, but it can also damage professional relationships.

From the research point of view Rode et al. (2003) suggest that it is advisable that the researcher has limited control over the selection of the children that participate in design sessions. According to them, it is best if children come from real classrooms so that they are familiar with each other and designing itself does not get disrupted by the unfamiliarity of others.

Iivari and Kinnula (2016) discuss children's genuine participation in technology design. They use a framework created by Chawla and Heft (2002), which is about the characteristics of effective projects for children's participation presented in Table 2. The model explains things that need to be considered when planning a project with participating children. Model's main goal is to provide different principles for children's efficient participation. The five main principles are *conditions of convergence* (issues with project establishment), *conditions of entry* (who are participated in the project and how), *conditions of social support* (ensuring that children feel accepted, valued and respect, *conditions for competence* (supporting competence and providing real possibilities to affect to the outcome) and *conditions for reflection* (ponder about decision making and reflecting things that happened during the project and why those things happened).

Iivari and Kinnula (2016) use the model of Chawla and Heft (2002) and discuss more how it fits in the school context and according to them, it is suitable for projects that concentrate more on learning goals than high-quality outcomes. Project members need to remember that school's main task is to enhance children's skills and ensuring that they become respected members of society. Teachers and schools should support the children's participation and give the opportunity to influence on issues. Thus, schools should be welcoming this kind of genuine participation projects in their environment. Dignified and respectable treatment to ensure learning should also be self-evident practice in schools and for teachers. Designers entering the school environment should take advantage of the teacher's pedagogical expertise.

Table 2. Characteristics of effective projects for children's participation (Chawla and Heft, 2002, p. 204).

- **Conditions of Convergence**
  - Whenever possible, the project builds on existing community organizations and structures that support children's participation.
  - As much as possible, project activities make children's participation appear to be a natural part of the setting.
  - The project is based on children's own issues and interests.

- **Conditions of Entry**
  - Participants are fairly selected.
  - Children and their families give informed consent.
  - Children can freely choose to participate or decline.
  - The project is accessible in scheduling and location.

- **Conditions of Social Support**
  - Children are respected as human beings with essential worth and dignity.
  - There is mutual respect among participants.
  - Children support and encourage each other.

- **Conditions for Competence**
  - Children have real responsibility and influence.
  - Children understand and have a part in defining the goals of the activity.
  - Children play a role in decision-making and accomplishing goals, with access to the information they need to make informed decisions.
  - Children are helped to construct and express their views.
  - There is a fair sharing of opportunities to contribute and be heard.
  - The project creates occasions for the graduated development of competence.
  - The project sets up processes to support children's engagement in issues they initiate themselves.
  - The project results in tangible outcomes.

- **Conditions for Reflection**
  - There is transparency at all stages of decision-making.
  - Children understand the reasons for outcomes.
  - There are opportunities for critical reflection.
  - There are opportunities for evaluation at both group and individual levels.
  - Participants deliberately negotiate differences in power.

The school environment might not be the best choice in projects where the material outcome is the most important result. Designers should choose a lab environment with a smaller group of children if companies are for example involved because their main goal usually is to create a final working product. Also, if designers have a strong desire for genuine participation then school context can cause some limitations due to the school's policies. In school children have quite limited decision-making capabilities, which may be a reason to work in a laboratory environment. It is also vital that teachers have to work extra hours for the project, so if a teacher does not have the desire for it then it can cause problems for the project. It is also a necessity that pedagogical goals are fulfilled or working in the school context may be difficult. Schools can be very rigid partners, thus planning, scheduling, initiating and collaboration inside the school can cause a lot of work. In school world children do not have an opportunity to choose which activities to participate or not. Therefore, a project that requires freedom of choice cannot be implemented in the school environment. (Iivari & Kinnula, 2016.)

4.5 The Actors and roles in designing in school environment

Druin (2002) created an influential model relating to children's roles in participatory design. The model called "the onion model" divides children's roles as *users*, *testers*, *informants,* and *co-designers*. When children are studied as *users* of technology, knowledge is gained relating to their practices and the importance of technology. The usability of the system and the importance of its' features can be measured when children participate as *testers* of the new technology. In the *informants'* role, children can be encouraged to create ideas for a new system during the design process. As *informants'* children act as information providers for the researchers or designers. Finally, in the design partner (*co-designer*) role, the children's voice is heard throughout the process by expressing their real-life experiences and expertise. Doorn (2016) recently added a role called children as *co-researchers* in design by sharing, gathering and enriching contextual data.

Iversen, Smith and Dindler (2017) introduce a sixth role, which is called the child as *protagonist.* In this role, children carry out the whole design process as *users, testers, informants co-designers,* and *co-researchers.* Iversen et al. (2017) also suggest that the *protagonist* role is more than just designing technological products; it is also meant for participants to develop new design abilities, insights and a reflective and critical stance toward technology through commitment in design work. Children also gain better understanding of technology and they make much more informed decisions relating to it in their lives. This also gives a possible approach relating to the challenge of training 21st century skills, which is heavily researched these days. Bekker et al. (2015) add that due to changing digital society the 21st century skills should be taught so that children are prepared for tomorrow's life. These skills include creativity, critical thinking, communication, teamwork and ICT and information literacy (Thijs et al., 2014 in Bekker et al., 2015).

This thesis has discussed a lot about children's, teacher's and school's role in design and making, but let us briefly discuss other actors also. Other actors are for example facilitators, researchers, university students, artists, parents, designers, peers, financial partners, governments, universities, scientists and companies. Facilitators are an important part of the design or making process, due to the support they give to children. Facilitators can simply encourage the work, help to use tools and materials. The facilitators should be well trained and develop their skills because their expertise shape's making the expertise of the children. Pedagogical skills are also highly valued feature for facilitators. (Bar-El & Zuckerman, 2016; Litts, 2015; Posch et al., 2010; Telhan et al., 2014.) Researchers role is to develop the research field and education relating to children learning design, making and technology (Druin, 2002; Litts, 2015; Wu et al., 2017). They organize the projects and sessions in the laboratory or school environment relating to making and design with children (Smith et al., 2015). During the projects, they document the process by taking notes and recording the sessions in later use (Smith et al., 2015). University students are used to supporting the researcher's work by providing manpower for the projects and research in general (Cheung et al., 2017). Artists are used to supporting children and educators in the technology design process with specific experience and expertise (Druin, 2002). Parents permit if their child/children can be researched during the process (Iversen et al., 2017), parents also transport the children around (Druin, 2002). Designers are used to supporting the design process (Read et al., 2016), they can act as partners in design for children sharing the responsibilities and concerns (Iversen et al., 2017). Peer learning or working in groups can also be thought of as an actor. Children can organize the groups by themselves or with the help of a teacher. (Fitton et al., 2015.) Children think highly of working as a group it enables to learn from each other and gain new ideas, but also it makes working more creative and enjoyable (Giannakos & Jaccheri, 2013). Then there are multiple behind the scenes actors such as financial partners, that finance and secure the operation (Litts, 2015). Governments are one decision-making body in setting curricula for schools and in defining strategies of education and innovation (Bekker et al., 2015). Universities and scientists give their input for developing theories, tools, and methods for teacher education and tools. Publishers, policy makers, companies, but also researchers develop a different kind of tools for design and making. (Bekker et al., 2015; Blikstein, 2013; Lassiter et al., 2013.)

5. Summary of prior research

In this chapter, the main topics from prior research are summarized. The summary is categorized into four categories, which are: process stages, goals, actors and school context. First, existing process models and stages are compared and combined which have been introduced in the literature review. Then the goals and objectives that this kind of design and making movement pursues are summarized. In actors' section, all the actors that participate in the process are listed. After that designing in a school context, its benefits and restrictions are summarized.

5.1 Process Stages

This section will summarize the process models introduced in the literature review. Innovation education is a movement for students and it is about finding solutions to problems and needs in our environment as Thorsteinsson et al. (2005) describe it. It suits also for redesigning or enhancing current products or solutions. IE develops students' innovation and ideation skills and it helps the student to take an active part in society and deal better with the world (Jónsdóttir et al., 2008). Thorsteinsson et al. (2008) introduced a seven-step model for innovation education working process. The seven steps are 1. Finding needs, 2. Brainstorming, 3. Finding the initial concept, 4. Sketching, modeling and developing the technical solution, 5. Making model/prototype, 6. Making poster and 7. Presentation. Design thinking is a method that presents a solution-based approach to problem solving and it is used to define unknown or ill-defined problems (Dam & Siang, retrieved in 2018). Hasso-Plattner Institute of Design at Stanford (d.school, n.d.) have introduced a model for design thinking that contains five stages, which are empathise, define, ideate, prototype and test. The model is iterative, and each stage should produce a deliverable outcome. Smith et al. (2015) and Iversen et al. (2017) introduce a design model that suits for the school environment. This iterative six staged model is created to support students and teachers to carry out a design process and gaining an understanding on the value for design thinking in teaching. The six stages are design brief, field study, ideation, fabrication, argumentation and reflection. Bekker et al. (2015) created a framework called reflective design-based learning (RDBL) inspired by Gomez et al. (2014) design-based learning model. RDBL is designed to support teaching in the primary and secondary school context. The RDBL has six factors from A to F which are as follows: A) The elements of a design process, B) Collaborative learning and reflection process, C) Learning goals and assessment, D) Design brief and project characteristics, E) Teacher's and children's role, F) Properties of learning environment including the digital toolkit.

The models above are combined into one framework as seen in Figure 9. The Figure 9 is an iterative reflective design process that can be used in fabricating or designing products and it is designed for use in a school environment. It is an iterative process and has 6 phases which are called 1. Design brief, 2. Field study, 3. Ideate, 4. Fabrication, 5. Test, 6. Presentation. Students should also reflect their actions during the whole process.

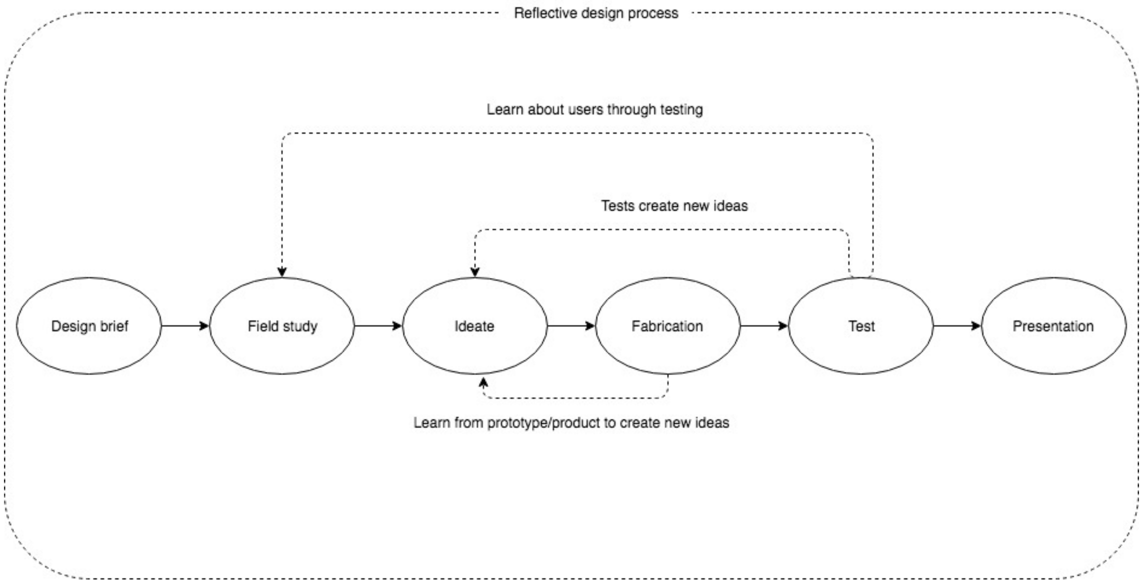


Figure 9. Reflective design process summarized from the literature review.

Bekker et al. (2015) and Smith et al. (2015) both include the stage "design brief" in their models. During the design brief ill-defined problems are described; problems that have various ways to be solved. Design briefing improves problem-solving skills and creativity (Gomez et al., 2013 in Bekker et al., 2015). Smith et al. (2015) mention that during the design brief phase students frame the complex challenge and the design process is planned.

The next activity is called "Field study" as in the article by Smith et al. (2015). During the activity users and context are researched and explored. Thorsteinsson et al. (2005) call this similar phase as "finding needs"; students search and identify problems or needs from their environment to work with. Hasso-Plattner Institute of Design at Stanford has named this step as "empathise" and in this stage, an empathic understanding of people is gained and the problem you are trying to solve. This understanding comes from consulting experts of the field and empathizing, observing and engaging with people to understand their motivations and experiences. The information gathered at this stage is used during the next stage to get the best possible understanding of the users, their needs and problems which determine the desired product. (d.school, n.d.) Even though the stages are called differently, they have almost similar purposes and therefore are named in this model as "field study".

The third phase is called "Ideate", a term used by d.school (n.d.). Smith et al. (2015) call this similar phase as "ideation" and Thorsteinsson et al. (2015) use terms "brainstorming" and "sketching, modeling and developing the technical solution". In this process, stage designers start generating ideas. With the previously gathered knowledge, designers can now start to think outside the box to find new solutions to the created problem statement and new ways to view the problem. Ideation techniques such as brainstorming are used to expand the problem space. During brainstorming, possible solutions are searched together with the support of the teacher. During the ideation phase the most important thing is to get many problem solutions or ideas as possible. In addition to brainstorming, students should ideate creatively using different technologies and materials. Students are encouraged to sketch, model and develop the technical solution to gain a better understanding of the concept and its' possible solutions; the phase involves self-communication and teacher support. (d.school, n.d; Thorsteinsson et al., 2015; Smith et al., 2015.)

The fourth step in the process is called “Fabrication”, which is the same as in Smith et al. (2015) process model. D.school (n.d.) call this phase a “Prototype” and Thorsteinsson et al. (2015) have named it as “Making model/prototype”. Students move to fabrication where mock-ups and prototypes are created using digital technologies (Smith et al., 2015). Thorsteinsson et al. (2015) add that the idea is not to fully develop them but to make a simple quick model to give an idea of the solution. The goal is to identify and experiment with the best solutions for the problems identified during the previous stages. The prototypes are then investigated and either accepted, re-examined and improved or rejected on the basis of users’ feedback. After prototyping designers will have a better understanding of the restrictions of the product, but also about the problems and better perspective how end users would think, behave and feel when interacting with the final product. (d.school, n.d.)

The fifth stage is testing and during this stage, the designers rigorously test the complete product. This is an iterative process and the results found often redefine the problems previously found. This is the last opportunity to understand the user, the conditions of use how people feel, behave and think, and to empathise. On these grounds, the final refinements and alternations are done for the product. (d.school, n.d.) Iversen et al. (2017) call this stage as argumentation, where students test the design ideas or products and reflect on the design arguments and moves of the process (Iversen et al., 2017).

The sixth and final stage is a presentation and during it, students make posters of their work for displaying their work and as a presentations’ basis. The poster also reflects an individual’s learning process. Posters include for example drawings, illustrations, and even 3D modeling. The poster explains how the solution works, where and who is going to use it, where and how it will be used, and what materials can be used creating it. Finally, the solution and poster will be presented to others. It helps students to understand the topic deeper, but it also challenges students to develop their communication skills and getting constructive feedback from others. (Thorsteinsson et al., 2005.)

As, can be seen from Figure 9 the process is iterative and can mostly be seen during test and fabrication phases. During fabrication, developers learn from prototype/product to create new ideas and return to the ideation phase to fill the shortcomings in the prototype/product. In test phase designers also can learn something new about users and their needs, so it may be necessary to go back into the field study phase. The test can also generate new ideas for the product, so developers go iteratively back into ideate phase. (d.school, n.d.)

Finally, students should reflect the whole process. Bekker et al. (2015) introduce *Collaborative learning and reflection process* and according to it, students should reflect their actions during the design activities and in between them. The idea is to support and ease the learning process of the student. The previously mentioned is introduced in an article called *Reflective Transformative Design Process* published by the authors Hummel and Frens (2015). Another great approach is Kolodner’s (2002) *Learning-by-designing,* where learners keep design diaries to reflect things they have learned during the process. Alongside the diaries, learners can use whiteboarding technique to reflect the progress and write down the key points they have learned. Smith et al. (2015) also mention that students reflect what they have learned and developed through the whole design process.

5.2 Goals

When talking about goals in making and designing in the school context, the biggest goal setter is the curriculum. The ways of working, design topic and results need to fit in the curriculum. Designing/making has to promote learning as a curriculum defines. In school context, one needs to remember that school's main task is to enhance children's skills and ensuring that they become respected members of society. (Iivari & Kinnula, 2016; Martin, 2015; Rode et al., 2013.)

Here are the main points of Finnish curricula in basic education. Basic education is compulsory education and it offers a wide general education for children. It guides students to find their strengths and to build their future based on learning. The mission of basic education is to teach and educate, to integrate a person into society and culture, and prepare for the future. (Opetushallitus, 2016.)

The goal is to learn, so motivation and personal interest in things are driving forces considering making and designing. Children are much more motivated when they are working with something needed by themselves. Learning can be seen as a byproduct that the interest in the making will provide. It is, therefore, a crucial goal to find the things that motivate one to work. (Papert, 1987; Thorsteinsson & Denton, 2003; Martin, 2015.) One of the goals is also to teach 21st-century skills for students. It teaches creativity, critical thinking, communication, teamwork and ICT and information literacy. Students learn to understand, use and evaluate technology, they gain ability to understand technological principles and strategies needed to establish recognize specific goals and solutions. (Bekker et al., 2015; Thijs et al., 2014; Voogt & Pareja Roblin, 2010.)

One goal is also to change the education in more student-centered direction, experimental and connected to the real world (at least, if teaching field of crafting) (Blikstein, 2013). The so-called passive learning where students memorize teachers teaching decreases student's critical thinking (Freire, 1974).

5.3 Actors

This section discusses actors and their roles that participate during the making, design or innovation process. This is summarized in Table 3.

Table 3. List of actors, roles and references.

Actor	Roles	References
Children	Innovators, designers, active learners, makers, users, testers, co-designers, informants, co-researcher, protagonist.	Thorsteinsson et al., 2005; Thorsteinsson & Denton, 2003; Schön et al., 2014; Martin, 2015; Druin, 2002; Iversen et al., 2017.
Teachers	Educator, facilitator, enabler, supporter, co-creator, coaching, pedagogical expert	Schön et al., 2014; Thorsteinsson & Denton, 2003; Kolodner, 2002; Gomez et al., 2013; Chawla and Heft, 2002; Iivari & Kinnula, 2016.
Schools	Educate, sets policies, give facilities	Rode et al., 2003; Blikstein, 2013; Chawla & Heft, 2002; Iivari & Kinnula, 2016.
Researchers	Develop research field and education relating to children learning design, making and technology. Develop different kind of tools for design and making. Organize the projects and sessions in laboratory or school environment relating to making and design with children. Document the process by taking notes and recording the sessions.	Bekker et al., 2015; Blikstein, 2013; Lassiter et al., 2013; Druin, 2002; Litts, 2015; Wu et al., 2017; Smith et al., 2015.
University students	Support, co-researchers	Cheung et al., 2017.
Artists	Support children and educators in technology design process with specific experience and expertise	Druin, 2002.
Parents	Permit if their child/children can be researched during the process, transportation.	Iversen et al., 2017; Druin, 2002.
Designers	Support design process, Partners in design for children sharing the responsibilities and concerns.	Read et al., 2016; Iversen et al., 2017.
Peers	Learning or working groups	Fitton et al., 2015; Giannakos & Jaccheri, 2013.
Financial partners	Finance and secure the operation	Litts, 2015
Governments	Decision-making body in setting curricula for schools and in defining strategies of education and innovation	Bekker et al., 2015
Universities	Develop theories, tools and methods	Bekker et al., 2015; Blikstein, 2013; Lassiter et al., 2013.
Scientists	Develop theories, tools and methods	Bekker et al., 2015; Blikstein, 2013; Lassiter et al., 2013.
Companies, Publishers, Policy Makers	Develop tools for design and making	Bekker et al., 2015; Blikstein, 2013; Lassiter et al., 2013;

The first column of the table explains what kind of actors were found from the prior research that have participated to making, design or innovative education. Next column called roles describe how these actors have participated and involved in making, design or innovative education. Third column lists the references where this data has been gathered and found.

5.4 School context

Chawla and Heft (2002) discuss children's genuine participation in effective participation of children in community development projects. The work of Chawla and Heft has been applied to technology development by Iivari and Kinnula (2016). They explain that school context fits best for projects that focus more on learning goals rather than high-quality outcomes. The most important thing in the school context is pedagogical learning. Schools and teachers should support students to take part in genuine participation and opportunity to influence on issues. In turn, designers should take advantage of teacher's pedagogical skills. As Rode et al. (2003) explain that a designer is all but in control about the situations and the environment when running design sessions in the school environment. Anything can happen when working with children, and one also cannot be sure that the desired classroom is available for sessions. This means that planning is so vital to avoid as many unexpected problems as possible. Schools and teachers also require that the sessions are carefully planned from the administrative point of view. Sessions need to fit into school policies and curriculum.

If the main goal is the material outcome, then the school environment is not the best choice. If economic benefits and final product are the most important results, then the laboratory environment is the most suitable place for working with children. Genuine participation in school context can also be quite limited, due to restricted decision-making capabilities that school policies adjust. Teachers also need to use their own time for these kinds of projects and if the teacher is not enthusiastic, then it will cause problems for the project. Finally, pedagogical goals need to be fulfilled and if there are no interest in doing so, the school environment is not the right place for this. (Iivari & Kinnula, 2016.)

6. Research method

This chapter explains the research method called qualitative research and how it is used in this research. Sub-chapter 6.1 will explain what qualitative research is. 6.2 explains how it is used in the project and the project itself is described. 6.3 tells how empirical data is gathered. Finally, 6.4 summarizes how it is analyzed.

The research question for this study is:

- What kind of a process model supports design and making in school context?

The models from the previous research are compared to the project's model and a model that supports this kind of design work in the school context is created. The process model focuses to identify the main stages of the process. One of the main interests also is what actors are taking part in this process and what kind of goals and motivations are the driving forces to it.

6.1 Explaining qualitative research

Drummond and Camara (2007) claim that the goal of qualitative research is to discover and understand new or different ways social realities emerge. It tries to investigate what life means to human beings and researchers think that there is a systematic way of understanding the problems that surround our society. It is impossible to understand every form of social phenomenon, investigation or question, but scholars can only research aspects that are accessible or available at the time of the observation. However, every researcher must approach their studies with as much ethical diligence, objectivity, and rigor as possible.

Qualitative research views the social aspects between persons in the relevant world. The relevancy can be seen as relationships and as semantic entities that they form. Semantic entities, in turn, are formed from people's events like activities, thoughts, creating goals or from social structures. The goal is to get data from their own real-life experiences. These experiences should hold the things that are important and relevant in a person's life. (Varto, 1992 in Vilkka, 2005.)

Lincoln and Guba (1985) have introduced so-called "human as instrument" approach. The focus is to understand human beings and their rich experiences and reflections. Qualitative research depends on thorough responses to questions about how participants understood or constructed their experience, so, for example, no categorized or force choice responses are used. This way of researching one gets much more information about the phenomenon compared to quantitative research. Unfortunately, the results cannot be generalizable to a population due to a few participants. (Lincoln & Cuba, 1985 in Jackson et al., 2007.)

According to Laine (2001), qualitative research should always consist of the question: What is the studies significance? Alasuutari (1994) adds that the special feature of the qualitative research is that it does not try to find the truth on the subject, but to interpret things from gathered data that cannot directly be seen during immediate observation.

Qualitative methodologies advice how studies should be done by pointing out what problems should be investigated, how to frame a problem how do create appropriate data generation and how to make a connection between the problem, data, analysis and conclusion. (Kaplan 1964 in Jackson et al., 2007.) Data analyzing methodologies that can be used are content analysis (what said), discourse analysis and narrative (concern for both content and form) to conversation (how something was said) analysis (Coffey & Atkinson, 1996 in Jackson et al., 2007).

Qualitative research has methods of data collection it includes interviewing for generating data from individuals or groups using unstructured, semi-structured or structured questioning formats. There are also group interviews called focus groups involving approximately 5 to 12 people. It focuses on the interaction between group members and questions are asked by the moderator. Next approach to gathering data is called a case study that can be favored in three cases: Why or how questions need to be answered by the researcher. The researcher has a little control over present-day real-life context that is studied. Also, in situations where the boundaries between the phenomena and context are unclear. (Yin, 1989 in Jackson et al., 2007.)

Another method is called fieldwork and it is practiced through participant observation and during it, the researcher gets to know the culture of participants. One needs to spend time in a setting, recording the daily activities of the people studied for the later analysis. (Stocking, 1983 in Jackson et al., 2007.) Other activities that can also be done during fieldwork are observing, listening, recording, conversing, interpreting and managing with ethical, logistical and political issues. (Wolcott, 1995 in Jackson et al., 2007.)

Ritchie and Lewis (2003) emphasize that there is no single right way of doing qualitative research. It actually depends on researchers' goals and purpose of the research, their beliefs about the nature of the social world, characteristics of the participants of research, environment, and position of the researchers, funders of the research and the audience of the research.

Finally, here are three straight definition quotes of qualitative research: "Qualitative research is a situated activity that locates the observer in the world. It consists of a set of interpretive, material practices that make the world visible. These practices transform the world. They turn the world into a series of representations, including field notes, interviews, conversations, photographs, recordings, and memos to the self. At this level, qualitative research involves an interpretive, naturalistic approach to the world. This means that qualitative researchers study things in their natural settings, attempting to make sense of, or to interpret, phenomena in terms of the meanings people bring to them." (Denzin & Lincoln, 2000, p. 3.) Second, comes from Bryman (1988): "The way in which people being studied understand and interpret their social reality is one of the central motifs of qualitative research" (p. 8). The third definition explains what qualitative research is not: "By the term 'qualitative research' we mean any type of research that produces findings not arrived at by statistical procedures or other means of quantification" (Strauss & Corbin, 1998, p. 11).

The project which was the basis of the thesis was mostly done using qualitative research methods. As said in the literature, this thesis views the social aspects between people in the school system, their relationships, actions, and goals. Lots of data was gathered about human beings, their experiences, and reflections. Many qualitative research data collection methods were used, but those are described in more detail in the next chapter.

One might think what kind of significance this study has. It introduces a process for designing and making in a class environment, which is best suited based on experiences gained in the project. A compiled design process was created from the literature review and compared it into project experiences in a class environment. From that comparison, a process model is introduced which introduces the best way to do design in a class environment. This work is important because the importance of 21st-century skills are increasing in modern society. This type of teaching in schools would be one of the best ways to support our children to learn 21st-century skills.

6.2 Research design

The project took place in autumn semester 7.9 - 19.12.2016 as a part of master's degree studies at the University of Oulu, Degree Programme of Information Processing Science. Project's stakeholders are master's degree students including me and three other students. Professor and a two University lecturers are the client representatives from INTERACT research unit at the University of Oulu. This aforementioned group in addition with a teacher from a primary school of Oulu forms the steering group of the project. The project goal was to familiarize school children with programming and digital fabrication while collecting research material for INTERACT research unit.

During the project 5 and 6 grade children designed, built and implemented a game spot for a board game, exploiting crafting materials and digital tools provided by INTERACT research unit, such as educational legos called Lego WeDo 2.0, Bare Conductive Touch Board, Makey Makey and Dash robot (which was used in programming with children). The projects climax was making some final designs in the Fab Lab of the University of Oulu. Both of the grades were divided into smaller groups, forming a total of 8 different groups; 4 groups for each grade. There were 22 fifth-graders and the sizes of the groups were Group 1: five students, Group 2: five students, Group 3: six students and Group 4: six students. There were 18 sixth-graders in turn, containing Group 1: four students, Group 2: four students, Group 3: five students, Group 4: five students.

Each of the project members took one group from both grades under management. Groups also fabricated artifacts for their game spots in University of Oulu's Fab Lab with help from the project group and a Fab Lab employee. The board game was executed at the primary school on two days in November 2016 with 5 and 6 graders respectively. Each session lasted for two hours and each group had their chance to host their game spot on their turn during gameplay. All the sessions were audio and video recorded, and reflected by the project group. There were 22 organized sessions entirely during this project divided for 5 and 6 graders. Sessions were called: Explaining information technology design process, game script sessions, designing the board game sessions, Fab Lab: implementing the board game, finalizing & assembling game spots, playing sessions and interviews.

6.3 Gathering empirical data

The empirical data was gathered from the 22 sessions which were held in primary school of Oulu, excluding the two sessions in Fab Lab located in the University of Oulu. The full list of gathered data are summarized in Table 4. The project managed to get permission to data gathering from every child's guardian/guardians that participated in the sessions for this thesis also. The fieldwork method was mainly used, but the case study was also utilized. The sessions started with a semi-structured starting questionnaire where children's current situations with information technology were investigated. A lot of participant observation was done during the project which gave a culture knowledge of the participants. It is also worth mentioning that every session was held in Finnish due to the fact that the school used it as the main language.

All the sessions were video and audio recorded, and afterward analyzed and reflected. Some photographing was also done in every session. Field notes were also taken, but there was not that much time for that due to group management in each session. Reflections were quickly done after every session because the field notes during sessions were quite impossible to write down. At the end of the project, a structured survey was done about the feelings that the project raised, along with unstructured pair interview to all who were able to participate in it. Children also reflected every session as a group by asking into questions such as: What was done? What did you learn? What was or was not fun? Also, children's design notes and artifacts were documented and gathered.

Table 4. Data gathered from the project.

Gathered data	**Amount**
Video	1436 Minutes
Audio	936 Minutes
Photo	238 Photos
Session plans	16 documents
Reflection documents	16 documents
Survey documents	2 documents
Interview documents	1 document
Steering group meeting documents	34 documents

This thesis is mostly focused on project documentation such as project plan, mid-report, final report, session plans, session reflections, timetable/workload documentation, guideline document which was created at the end of the project and photos. It will not focus much on audios, videos, the documents of children's ideas and end results (the artifacts/games children created), surveys and interviews.

6.4 Analyzing the empirical data

Content analysis was used in the thesis as the data analyzing was done from the stored project documentation located in the external hard drive that was included at the end of the project. The project documents were read through and the most interesting topics that best supported writing this thesis were selected. Those topics were then opened up for the chapters 6 to 9 respectively.

The project documentation was used as a reminder of the things that were done during the project. The focus was to find the process stages, actors involved, motivations and goals that were set for the project, and the details regarding designing and making in the school context. The most suitable documents that were analyzed were session plans and reflections, project plan, mid-report, final report and project's workload document. These documents described the process stages that were done in different periods of time. The actors, school context and other resources used during the project were analyzed from these documents.

In addition to the previously mentioned documents, steering group meeting minutes, client assignment document and research permit document defined the goals of the project. All the photos that were taken were analyzed and picked up the pictures that would be used in this thesis. The video and audio documents were not used at all and there was no purpose of analyzing the interviews also in this thesis.

7. Designing and making a project with children

This chapter will point out the project that is the basis of this thesis. It is divided into five sub-topics which are:

1. Describing the project
2. Process stages
3. Goals
4. Actors
5. School context

First sub-topic describes what the project was all about and how it was done. The sub-topics from 7.2. to 7.5. are same topics summarized in the literature review's chapter 5., namely Process stages, Goals, Actors and School context and in this chapter, the topics highlight the experiences and insights from the project. Finally, the findings and results of the project are reflected whether there are similarities and differences compared to the literature review.

7.1 Describing the project

In section 6.2. it was briefly described the project that, during the project 5 and 6 grade children designed, built and implemented a game spot for a board game, exploiting crafting materials and digital tools provided by INTERACT research unit, such as educational Legos called Lego WeDo 2.0, Bare Conductive Touch Board, Makey Makey and Dash robot (which was used in programming with children). The projects climax was making some final designs in the Fab Lab of the University of Oulu. It is now described more specifically how things went in the project.

INTERACT research unit ordered a project from the Degree Programme of Information Processing Science. Their instruction was to organize a project with children, including, designing, making, programming in collaboration with school and INTERACT research unit while gathering research data. In a very limited timeframe, it was decided to design and make a following digital board game entity, but also introducing rudiments of information technology design processes. The design process of the project which included 22. sessions (interviews not included), were done like this:

- Introduction session (1. Session)
  - Planning
  - Session
- Explaining information technology design process (1. session)
  - Planning
  - Session
  - Documenting
  - Reflecting
- Game script sessions (3. sessions)
  - Planning
  - Session
  - Documenting
  - Reflecting
- Designing the board game sessions (3. sessions)
  - Planning
  - Session
  - Documenting
  - Reflecting

- Fab Lab: implementing the board game (1. Session)
  - Planning
  - Session
  - Documenting
  - Reflecting
- Finalizing & assembling game spots (1. session)
  - Planning
  - Session
  - Documenting
  - Reflecting
- Playing sessions (1. Session)
  - Planning
  - Session
  - Documenting
  - Reflecting
- Interviews (1. session)
  - Planning
  - Executing

The process was done for both of the grades separately. In the first session, project members were introduced themselves to children, the concept of the Fab Lab was also briefed, and a starting survey was made about former experiences of computers, mobile devices, and programming. After that, the idea was starting to emerge of what this project would start to design with the children. Then a session called "Explaining information technology design process" was arranged, and during the session the design process models such as waterfall model, spiral model and Participatory Action Research (PAR) (Delgado & Paragulla, 2016) were introduced, the PAR will be explained more precisely later on. Then the board game idea and the tools seen in Figures 10 and 11 were introduced (Lego WeDo 2.0, Bare Conductive Touch Board, Makey Makey, and Dash robot) which brought the digital aspect for it. Even though process models were used and introduced, there was no intention to bore the children with the models, but to keep things as playful as possible. It was a little hard to motivate some kids in the early phases of the design, but the motivation levels increased during the implementation phase at the least. It was also a natural choice not to use too technical language during the sessions.

Figure 10. Bare Conductive Touch Board, Makey Makey and Dash robot.

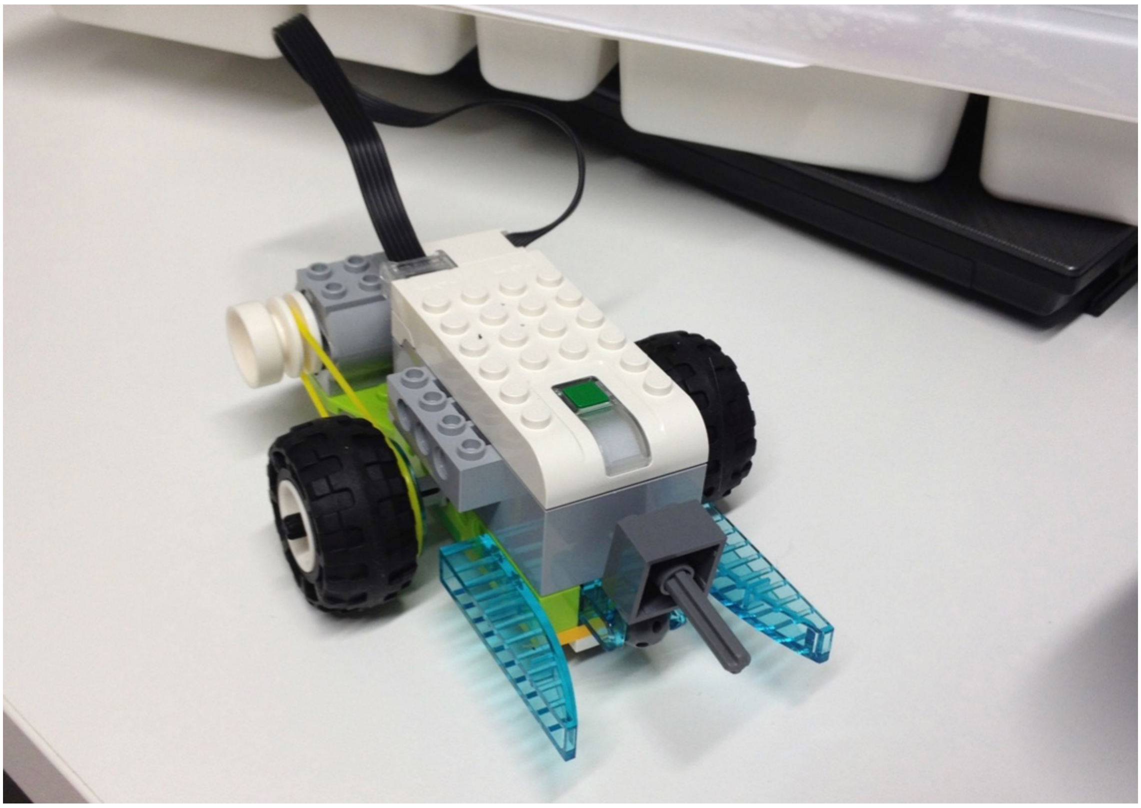


Figure 11. Lego WeDo 2.0.

From here on the PAR model was implemented in junior researcher peers. The PAR's steps were 1. Planning of the sessions, 2. Executing the sessions, and 3. Reflecting the Sessions. The PAR was then used during the whole project. The structure of the sessions with children was: 1. Introducing the day's topic, 2. Designing, and 3. Reflecting the day's work.

Three sessions called "Game script sessions" were then arranged and during the sessions, each group planned and scripted their own part of the board game. Children planned their theme of the game and how it will be played through. Then there were three "Designing the board game sessions". During those, children started to plan how they would execute the game, but the main focus of the sessions was in designing the actual game so that everything would be ready for the Fab Lab visit. During one design session children got their hands on to the digital tools (Figure 12), where they tested how they would use them in their games. Before the Fab Lab session, every group had planned (some more than others) things they would implement for the game in Fab Lab.

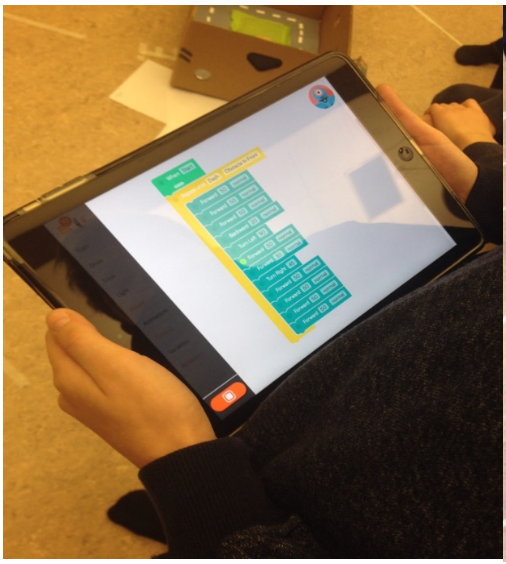
Figure 12. Programming Lego WeDo 2.0

The session "Fab Lab: implementing the board game" was held in the University of Oulu and children executed their plans during the session with the support of junior researchers and the facilitator of the Fab Lab. It is worth mentioning that, in the introduction stage of the process the approvals for using these pictures were gathered, parents were informed about the ethical issues such as consent forms. Also, regarding the working in Fab Lab, the teachers and children as well as junior researchers knew about the safety behaviors in Fab Labs. Figure 13 shows how children design objects which are eventually printed out with 3D-printer. Laser cutter which is presented in Figure 14 was a most used tool in the Fab Lab among children.

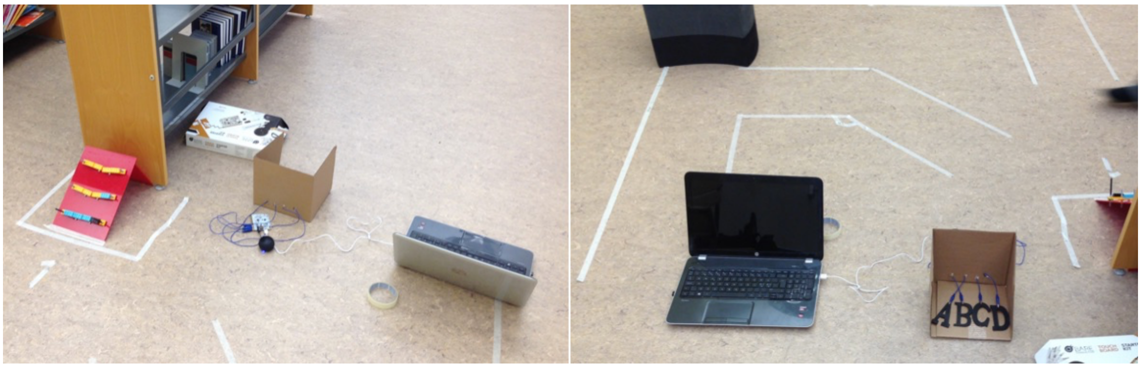
Figure 13. Designing in the Fab Lab with Tinkercad.

Figure 14. Laser cutter.

Then it was time to finalize the game in: “Finalizing & assembling game spots” session so that the games would be ready into the final sessions: “Playing sessions”. The playing session was scripted like this: each group had a board game that was a part of a larger entity. In other words, both of the grades had a one big board game which was divided into four smaller game spots. One of these game spots can be seen in Figures 17 and 18 As you can see from Figures 15 and 16, each group had their own turn to face the programming task with Dash Robot to move into the game spots within the lines.



Figures 15 & 16. Programming with the Dash Robot.



Figures 17 & 18. Game spot called: Quiz.

To be more precise, when each group had their own turn to introduce and administrate their own game spot, they first had to complete the programming task. Dash Robot was used as a pawn during the play session. At the end of the project, one interviewing session was held with children. Children were interviewed about their opinions, experiences, and feelings about the project and this kind of design work. The interviews were not utilized in this thesis, because they did not give any answers to the research question set for this thesis.

7.2 Process Stages

The session list looks much like a waterfall model, where things are done one phase at a time without iteration. There are a lot of similarities with the waterfall model, but with the certain iterative element is present. Figure 19 describes the session list as a process model.

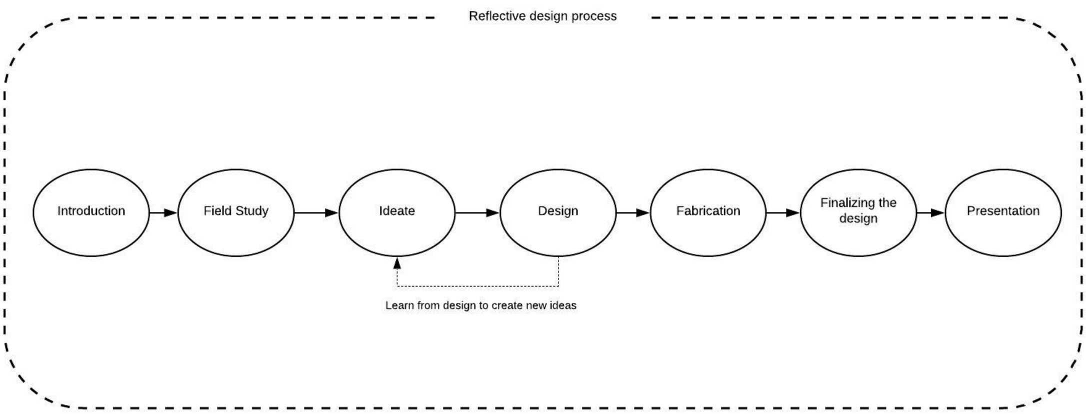


Figure 19. Project's reflective design process model with children.

As you can see from the design process model, the introduction is the first stage in the project. It included both the introduction session and explaining the information technology design process. Game script sessions have been divided into two stages in this model and those are field study and ideate. It is divided because during game script sessions children did both: researching and exploring the context, but also ideating the game itself. Designing the board game sessions is named simply a stage called design. During the design stage children learned more about the design and idea behind it. In most of the cases, children learned from the design to create new ideas. The fabrication part would also fit into the design stage, but as there were big focus and aim on the fabrication (The Fab Lab), it will be included as an own stage. It was also a very much different designing than the previous ones because first of all it was held on its' premises and it included the Fab Lab machinery. To put it briefly, fabrication (making) as a term means different things than design as was mentioned in the literature review before. The project was also forced to organize finalizing and assembling game spots session (in the model it is called finalizing the design) because most of the designs were not completely ready before the fabrication stage. The final stage is a presentation, which contained the playing sessions. The whole process was done reflectively so that children were reflecting as a group their own learning process. They reflected into questions: What was done? What did you learn? What was fun? What was not fun? What ideas were developed during the session?

These stages of the process were decided from the early phases of the project. In the final version of the project plan, all of the stages were already included with the exception of finalizing the design stage because it had to be included during the process. There was not any particular design process model that was used throughout the project. It was a mix of everything known about design process models and it was decided to do this waterfall type of process model where executing would go one stage at a time. It was simple enough for children to understand. It was thought that too much iteration would confuse the children.

7.3 Goals

This section goes through the goals that were set for the project. The goal of the project was to introduce digital fabrication and information technology design process to school children and staff by designing and implementing a digital board game with 5th and 6th-grade students and at the same time gather research material for the INTERACT research unit in the University of Oulu. The research unit was more interested in research material than the outcome of the project with children.

The idea (discussed by Bekker et al., 2015; Thijs et al., 2014; Voogt & Pareja Roblin, 2010) was that children had to use their already existing 21st century skills and to learn some new ones during the project. Children had to design and execute a project where they applied their previous knowledge, skills, and creativity about programming and functional mathematics in together with other technical skills, art and storytelling. The school itself was interested to expand math teaching to technology education. This specific primary school also aimed to teach entrepreneurship for children and that fitted also for the project's goals.

It was also vital that this kind of design and making project would fit into the curriculum set by the Finnish National Board of Education (Opetushallitus, 2014). Programming became part of the Finnish school curriculum from the fall of 2016 and INTERACT research unit was inspired to have a broader approach and try out a mixture of teaching children design thinking, digital fabrication (making) and programming in cooperation with schools. As mentioned in the projects' research permit document; nowadays people use a different kind of technology in everyday life. Technology has many forms, usually, it is visible, but many times it is out of sight without thinking about its presence. Different kind of media such as social media is familiar for many of us since early childhood. Therefore, INTERACT research group was interested in what kind of this swiftly changing, technology-mediated, modern communal life is today for different people and how they can be involved in forming their own life. In this case, the children created information technology solutions in school and the Fab Lab. INTERACT research unit pointed out that, there has not been much research about Fab Lab with children in Finland.

They also wanted more data relating to project working in a school environment; what kind of roles teacher can take and how to collaborate with teachers.

As Papert (1987), Thorsteinsson and Denton (2003) and Martin (2015) mentioned in the literature review, that children's motivation is a key factor and goal in this kind of work. One of the goal was to help children to find things that would interest and motivate them. Genuine participation by the project members was also a goal, because it motivates children even further and as Schön et al. (2014) said that the role is not to be teachers, but more like facilitators and enablers that support and give tutoring to children.

7.4 Actors

As compared to Table 3 (List of actors, roles and references) collected from the literature review, most of the same actors can be found from the project. Table 5 shows the actors and their roles in the project. The project did not specifically include full-time artists and designers. The roles of those actors were done mostly by project members, but during some sessions school teacher and researchers also took that role.

Table 5. List of actors in the project

Actor	Roles
Children	Innovators, designers, active learners, makers, users, testers, co-designers, informants, protagonist.
Teachers	Educator, facilitator, enabler, supporter, co-creator, co-designer, co-artist, coaching, pedagogical expert.
Schools	Educate, sets policies, give facilities.
Researchers	Develop research field and education relating to children learning design, making and technology. Develop different kind of tools for design and making. Organize the projects. Document the process by taking notes and recording the sessions. Other roles: Facilitator, co-designers, stakeholder, client.
Junior researchers	During sessions with children: support, facilitator, enabler, supporter, co-creator, co-designer, co-artist, coaching/tutoring. Other project roles: Project management, organizing the project, document the process by taking notes, recording and reflecting the sessions, general project documentation, communication between stakeholders.
School assistant	Support, co-creator.
Parents	Permit if their child/children can be researched during the process, transportation.
The Fab Lab facilitator	Co-designer, co-artist, facilitator, enabler, coaching/tutoring.
Junior researcher peers	Working group.
Children peers	Working and learning groups.
Financial partners	Finance and secure the operation.
Governments	Decision-making body in setting curricula for schools and in defining strategies of education and innovation.
University	Develop theories, tools and methods.
Scientists	Develop theories, tools and methods.
Companies, Publishers, Policy Makers	Develop tools for design and making.

The facilitator of the Fab Lab acted also as an artist and designer during the Fab Lab sessions and will be included to the list. Another new actor that had a minor role in one design session (due to redundancy) during the project is called school assistant and it will be included to the list. Actor: "Peers" will be divided into two: "Project member peers" and “Children peers”. The actor “University students” is also changed to “Junior researchers”.

7.5 School context

The primary school in Oulu and the teacher of optional mathematics was interested to co-operate with the University of Oulu with this kind of project. The school was interested in technology education and optional mathematics was a fitting course to carry out the project.

Iivari and Kinnula (2016) mentioned that school context is best for projects that focus more on learning goals than end results and outcomes. The idea of the project was to be suited for school context so that it would fit into the curriculum and the main focus was not in the outcome. In school perspective, the process of design work was introduced for both children and school staff as was planned**.**

When looking from the design point of view, the school set a lot of restrictions, but that was the idea of the project all along and must not be taken as a negative aspect. One of the project’s goals was to gather data about how this kind of project working fits into the school environment. The biggest restriction was curriculum and school policies as suspected by the previous research. The project had to be planned a way that it fitted into the curriculum. Every session plan also needed to be shared for the teacher before the sessions, so that she could check if anything had to be changed.

Researching in the school environment is very challenging and need to be planned carefully before sessions so that it will not take too much from the session itself. It is vital that you check the classroom before the sessions, so you know where to place up video cameras and audio recorders. Classrooms are very noisy when there are a lot of children around, so in the sake of research material, you should have more than one classroom to divide the children between them. Less noise helps everyone to concentrate better as well.

8. Discussion

The research question for this study was:

- What kind of a process model supports design and making in school context?

In this chapter, the summarized model from the previous research (Figure 9) and the project's model (Figure 19) are compared and discussed. The answer for the research question comes from these two models, as they are combined as one final model that supports this kind of design process in a school environment. This model should be applied according to resources that are available and due to that it does not have to be strictly followed. The chapter also discusses actors, school context and goals that support the model.

Finally, it is generally discussed how this kind of project work that includes design and making would fit in the school environment in a way that does not include researchers. Meaning that school children would be self-sufficient enough to clarify for themselves without having any help from outside of the school environment.

8.1 Final process model

The process model from previous research and the project has a lot of similarities, but also differences. The biggest similarity is that both of them are reflective processes during the whole lifecycle. This means that children reflect their own learning process of design and making. Both of the models also have a basic structure of studying the field where context and problem are researched and explored, ideating the design, design/making and presenting the outcome in playing session or presentation session. Biggest differences when comparing the project's model to previous research is that it includes an introduction to the topic by junior researchers and finalizing the design stages, it also does not include testing. Project's model is not that iterative compared to previous literature model. The only iteration is between ideate and design stages; comparatively the model of previous research has iterations between field study – test, ideate – test and ideate – fabrication.

The introduction needed to be done, because the children in the primary school did not have much of previous knowledge of design/making processes. In some cases, there would not be much or even any need for introduction stage, for example, if a similar project would be done with the same children or a new group of children who already have experience of this field. Due to the lack of human and time resources, the project was not able to include much iterative working or testing. Another reason for the lack of time was that much of it had to be used in project planning. The client (INTERACT research unit) hardly gave any direction where to go with the project. The project group had to rush with the decisions so that there would be at least some time to plan and design with the children. The biggest negative restriction was the length of the optional mathematics class. There was only an opportunity to arrange 45-minute sessions, with few exceptions. This turned out to be a problem because session introduction and reflection parts had to be rushed to have enough time for planning and designing. Also, the classes were only once in a week and there was a very strict finishing schedule that University set for the project. The INTERACT research unit and school planned that both of the grades should take part in the project and that generated some problems too, this mostly affected in lack of tools. Tutoring eight groups became a bit hard handle. Junior researchers had to concentrate the energy entirely to supporting and tutoring. There would have been much more time for better researching and better children's design outcomes, for example with four groups. This was especially rough when some of the members got sick during the project. The children were also maybe too young for this kind of work and probably too much held needed to be given so that they would accomplish the board games. Children were not able to understand their own skills and the ideas were usually a little bit too unrealistic. The lack of time was very stressful, but at the end very rewarding experience once the challenge was over.

The only difference that would be made is that the time would be used more wisely. The frames for the design and project would be planned before starting the sessions with children because it effects into everything if you start the sessions without even knowing what is going on and what you are about to do. This could give better research results, learning outcomes and artifact results for the children. With the previous in mind, a model is now introduced in Figure 20 which supports the work in a school context based on prior research and experiences gained from the project.

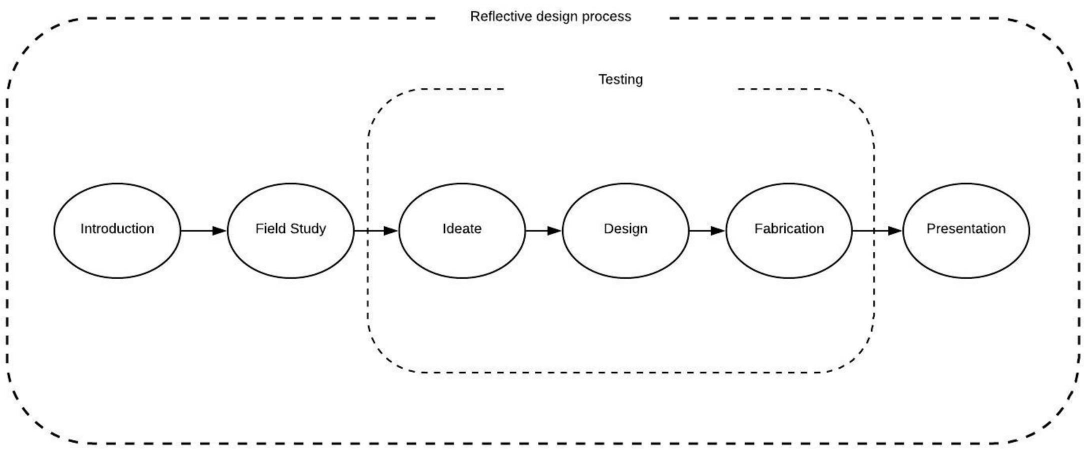


Figure 20. A model of design and making in the school context.

The model is otherwise the same as the project's model, with a difference of including iterative "testing" and by removing "finalizing the design" stage due to the fact that it was originally added because of compelling circumstances. The purpose of the iterative testing is that children: 1. Create an idea, 2. Design some of it or entirely, then test if the design resolves the problem and works as planned, 3. If not, then children ideate using the newly gained knowledge and design again. 4. Finally, children will go to Fab Lab or other digital fabrication laboratory and do the making part of the project. Testing is also done during or after the fabrication stage and children then go forward to the presentation stage or previous stages depending on the testing results.

Working with this kind of project in a school context involves a lot of actors as can be seen from Table 5. That is a lot of actors to think about if you come outside the school environment. It would not be such a radical difference in the situation, if these projects would come inside the school system. Every actor that is needed would already be there in a first place, with an inclusion of the Fab Lab facilitator that definitely is needed, in the beginning at least. In an ideal situation, the only change to Table 5 would be that everything related to researchers and junior researchers could be removed from the list.

When thinking about a school context and whether making and designing would work better in a laboratory or a school environment. There can be many benefits of working in a school environment. School as an environment and teacher as a person provide the authority and pedagogical skills that are needed. On the project, this extra authority was a big advantage because in the project group I only had a little pedagogical experience as a school assistant and had done a Basics of Educational sciences. Otherwise, the junior research group did not have the pedagogical know-how and there would have been a lot of problems if this kind of project would have been taken place in a laboratory environment. The teacher also knew the children before and had the knowledge of how to form the groups the best way possible. This enabled us to concentrate much more on the topic than solving the conflicts between the children. It was also beneficial, that children knew each other before and there were no shyness and communication was good between them. The flip side of children knowing each other was that there was a lot of playing around and teasing one another. Another important thing in the project was that the teacher was very interested and passionate to participate in it, she even used her free time from work to participate during it. On the other hand, as Iivari and Kinnula (2016) mentioned that, if the final product and economic benefits are the most important results, then the laboratory environment is the most suitable place for working with children.

Main goals that support this line of work from the upper level is to have more skillful programmers, designers, makers, introducing this kind of design and making projects to school environment. Goal is to utilize and teach more 21st century skills to youth.

From the teaching point of view, it is important to make this playful process where children can find their joy and motivation to design and making. Topic needs to be interesting and related to their life and surroundings. As a teacher or a facilitator, the goal is to be present and participate. Be supportive, let the children find the solutions, do not give your ready designs. Make the teaching student centered and not teacher centered. The main goal is that children learn about the process, tools, ways to work, the final product is not important in the beginning.

8.2 The Fab Lab to Finnish schools?

At the time this thesis is written there are seven Fab Labs in Finland meaning that there are not many possibilities to do only fabrication/making in the school environment[1]. According to the footnoted Fab Lab website, there is at least two primary schools in Finland which have their own Fab Lab, both of them are located near Oulu, one is called Vesala school in Ylikiiminki and second is located in the school of Yli-Ii. The other Fab Labs are located in Helsinki, Tampere and two in the area of Turku. Seven Fab Labs is not much, but a huge improvement from the days of the project. In 2016 there were only two Fab Labs, one in Aalto University of Helsinki and the other in the University of Oulu. The ideal thing would be that schools would not have to do the designing and fabrication separately in different places, but to have the Fab Lab on school premises. Children could, therefore, do the whole ideating, design and fabrication part in Fab Lab and this would potentially remove the so-called “Design” stage from the model and would be replaced only with “Fabrication” stage. The aspect of having continuous availability to Fab Lab would make “Design” stage meaningless, because “Fabrication” stage includes the

[1] https://www.fablabs.io/labs?country=fi

design. The project that we did with children was a nice introduction for Fab Lab and fabrication for sure, but the real benefit of it really did not have a chance to emerge. The children had a possibility to see and experience the lab and do something in there for the three hours we had, but that was all. Imagine a project where the Fab Lab is introduced at a day one of the projects and can actually work there the entire project. All that can be done is to refer to a project that did not have this opportunity. The children had a hard time to really understand what Fab Lab is and what can be done in there, even though we tried to introduce it during the sessions. They were not able to plan and design their artifacts with the Fab Lab tools in mind. We (junior researchers) had to think on children's behalf what they would do there, what tools to use and how to use them. It would be a very different situation if children would have the opportunity to get familiar with the lab during the project. They could ideate their design with the tools in mind, they would have a better understanding of the limits and potentials of the design. They would know better if something is doable or not. In any case, the fabricating and learning results would be much better due to a better understanding of the tools. In our project, we did not have this opportunity, but hopefully, this gave some motivation for the children on future opportunities and some of the children even suggested so during the interviews we had at the end of the project.

So, would it be possible to introduce digital fabrication (Fab Lab) and design work in primary school and high school environment? Well in Finland this has been done at least in Ylikiiminki and Yli-Ii, but could this be introduced for the whole country? What needs to be taken into account, so that this could be done without researchers and other experts on the field? Could primary and high schools one day be self-sufficient enough to teach this field without any outside help?

What it would require introducing Fab Lab to schools? Let us discuss the thing that everyone thinks first, how much this would cost? According to the website[2] Fab Lab community: "Equipment costs average about $25k to $65k, and about $15k to $40k for consumables." In Euro's the cost of equipment would be approximately about €22k to €57k, and for consumables: €13k to €35k. That is a lot of money to pay at once for sure, but on a longer period of time it is not that much.

Another big question is that who would teach this to children? In our project, the guidance came from us (junior researchers) and the facilitator of the University of Oulu. Schools cannot relate and use researchers if they implement Fab Lab on their premises in the future. One option is that schools should hire a full-time Fab Lab facilitator, the other is to educate our class teachers to use the facilities. For example, the University of Oulu offers a handicrafts/technical work/technology as a minor subject study for the University students[3]. In Rauma, one can even do subject and advanced studies in handicraft[4]. The

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[2] http://usfln.org/start-a-fab-lab/

[3] http://www.oulu.fi/edu/technical_work

[4] https://www.utu.fi/fi/yksikot/edu/yksikot/okl/opiskelu/oppiaineet/ks/Sivut/home.aspx

thing we would have to do as a nation is to introduce digital fabrication as a subject in our University education studies. This way our class teachers (who have chosen to study the subject in University) would have the knowledge to run the Fab Lab on their own.

The model that was produced would be best suited for a long-term subject that would last for half a school year for example. During the longer time period, there would be enough time to introduce all of the model stages, learn about the design process and working in Fab Lab. The teaching of digital fabrication could be done similar ways than teaching handicraft is done today; from 1st grade to 9th grade. Basic handicraft teaching can be a bit outdated and it could be integrated into digital fabrication, or at least the other way around. The design process, making, designing, programming etc. would become very familiar during those years.

The idea of implementing this kind of design/making work to the Finnish school system is not that surreal thought, just look what Iceland has done during the years. The Innovation Education that was introduced at chapter 2 is not far from what have been suggested. The seven stages used in Innovation Education are almost similar to what have been introduced in the model at the beginning of this chapter. The biggest difference is that it includes digital fabrication in form of the Fab Lab. Maybe we can learn something from them as they are pioneers in this? Using and creating new technology is the future after all.

9. Conclusions

The outcome of this thesis is a model that supports design and making in a school context but also discuss what kind of actors and goals are related to this process. First, I explained the meanings of innovative education, design, and making. I explain how to use them in a school environment with children and the pedagogical aspects related to them. Then I compare the summarized previous knowledge to the research project we did in 2016. The project was about ideating, designing and making a digital board game using digital interactive tools, different crafting materials, and the Fab Lab. The final process model is based on the experiences of the project and previous research.

The biggest limitation in a global perspective is that every country has its own school system and curriculum and this thesis has done only at the Finnish school system and curriculum in mind. There cannot be too big insurmountable differences between countries that would prevent this kind of project from happening. This model is also based only on experiences received from one school and one project. I have not also tested my model in real-life, so I cannot really prove if it is better than the previous ones, but that could be tested in future researches.

In future research, I would go and study the schools of Ylikiiminki and Yli-Ii or any school that has Fab Lab in the future. I would study the pros and cons of this kind of design work, using the model I created or any other model that suits best for them. This would give the best data whether there is potential or not in implementing design and making in school context. Teaching design and making would perfectly fit in the new Finnish curriculum because programming was included in it. The movement called Koodi2016 (Liukas & Mykkänen, 2014) tries to explain why coding is important and how to teach it, the movement is supported by huge companies such as Rovio and Supercell. As said in Koodi2016, programming is not a subject of its' own, but a part of mathematics teaching. In my opinion, programming should have its' own subject in primary schools, due to the lack of really skillful programmers. Design and making would support this cause because it includes programming, but children also learn about project working and design processes.

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